

TILLAGE AND MULCHING EFFECTS FOR MONO AND MIXED CROPPED MAIZE (*Zea mays*) AND COWPEA (*Vigna unguiculata*) SYSTEMS: EFFECTS OF CONSERVATION AGRICULTURE ON PRODUCTIVITY AND WATER USE EFFICIENCY



Name student: Vengai Mbanyele

Period: September 2013 – August 2014

Farming Systems Ecology Group

Droevendaalsesteeg 1 – 6708 PB Wageningen - The Netherlands

**TILLAGE AND MULCHING EFFECTS FOR MONO AND MIXED
CROPPED MAIZE (*Zea mays*) AND COWPEA (*Vigna unguiculata*)
SYSTEMS: EFFECTS OF CONSERVATION AGRICULTURE
ON PRODUCTIVITY AND WATER USE EFFICIENCY**

Name student:	Vengai Mbanyele
Registration number student:	820227548010
Credits:	36
Code number /name course:	FSE-80436
Period:	September 2013 – August 2014
Supervisor(s):	Dr. J. Scholberg (FSE – WUR) Prof. P. Mapfumo (SOFECSA – UZ)
Professor/Examiner:	Prof. P. Tiftonell

Table of Contents

Abstract	ii
Acknowledgements	iii
List of abbreviations	iv
1 Introduction	2
2 Materials and Methods	5
2.1 Experimental sites	5
2.2 Experimental design and layout	6
2.3 Tillage treatments	6
2.4 Mulching treatment	6
2.5 Cropping treatment	7
2.6 Measurements	7
3. Results	10
3.1 Rainfall	10
3.2 Soil bulk density	11
3.3 Soil available water content	15
3.4 Leaf area index (LAI)	18
3.5 Above- ground dry matter accumulation	20
3.6 Grain yield	24
3.7 Land productivity	28
3.8 Soil organic matter (SOM) content (%)	29
4. Discussion	32
4.1 Rainfall	32
4.2 Tillage and mulching effect	32
4.3 Cropping systems and WUE	34
4.4 Land productivity	35
4.5 Soil organic matter content	35
4.6 Effects of CA on crop productivity	35
5. Conclusion	37
References	38
Appendix 1	41
Field layout at study sites	41

Low crop productivity of rain-fed crops is one of the greatest challenges smallholder farmers face in Zimbabwe. This study assessed the interactive effects of two contrasting tillage methods and mulching on the productivity of mono and mixed maize-cowpea cropping system under semi-arid rain-fed conditions. The tillage methods under study were reduced tillage through ripping and conventional ploughing up to a soil depth of 15 cm. Mulching treatment had two levels corresponding to leaving the soil surface bare vs mulching which implied covering 30 % of the soil surface with 2 t ha⁻¹ of cut grass from common thatching grass (*Hyparrhenia hirta*) plant residue at crop emergence. The cropping system included either mono crops of maize and cowpea or an intercrop of these two crops. The study was conducted during the 2013/14 cropping season as an on-farm experiment in Wedza district (Eastern part of Zimbabwe) at the Dendenyore and Ushe wards. The design of the experiment was a split-split plot with tillage as the main plot, cropping system (sub-plot) and mulching (sub-sub-plot) at both sites. For each treatment, periodic measurements of soil bulk density and available water content (gravimetrically) in the top layer of the soil as well as above-ground crop biomass was obtained. The Leaf Area Index (LAI) was determined at the peak growing stage of the plants (i.e. just before flowering) while grain yield was determined at crop maturity. Water productivity was determined on the basis of the above ground biomass (WUE_{DM}), total grain yield (WUE_{YLD}) and crop-based revenues (WUE_{ECON}). The crop-based revenues were calculated on the basis of local grain prevailing prices of the two crops at harvesting. The 2013/2014 cropping season was relatively wet with sites receiving rainfall amount of 642-650 mm just during the growing season. There was an interaction of tillage, mulching and cropping system with regard to crop productivity. The maize-cowpea intercrop under mulched-conventional tillage was the most productive combination at all sites in terms of above-ground dry matter and grain yield; though yields were not significantly affected by mulching. In terms of income as well as WUE_{ECON}, conventional tillage system achieved about 70 % and 160 % higher values compared to corresponding reduced tillage systems at the Dendenyore and Ushe sites, respectively. The Land Equivalent Ratio (LER) exceeded one for the intercropping systems at both sites which implies more land productivity and yield advantage of intercropping compared to mono-cropping. Therefore it is concluded that maize-cowpea intercropping, when combined with the mulched conventional tillage, may improve crop productivity per unit area. However, these findings may have to be confirmed by follow-up studies for consecutive seasons to also include drier seasons to better assess benefits and impacts under more water-limiting conditions.

Keywords: reduced tillage, conventional ploughing, water use efficiency, land equivalent ratio, intercropping, mono cropping.

Acknowledgements

I wish to thank Soil Fertility Consortium of Southern African (SOFECSA) that made this study possible by providing funding through their ABACO project. Special thanks to my two supervisors Dr. Johannes Scholberg and Prof. Paul Mapfumo who helped me throughout this thesis research by providing guidance.

I wish to also thank Dr Mutambanengwe, Mr Nezomba, Mr Rurinda and other SOFECSA team members (Mr Mutangadura, Mr Chagumaira, Mrs Manzeke and Mr Mbiza) who assisted me during my thesis research. Cooperation of two farmers (Mr Ngwenya of Dendenyore and Mr Mukandi of Ushe) who provided their fields to host this study is also highly appreciated

The contribution of my life partner Rebecca and our son Anopa Lyle is also greatly appreciated during the course of my study. Above all, glory to God for the gift of life and the strength He gave me throughout the study period.

Last but not least, I wish to thank Mr Halm Hennie of Farming Systems Ecology, Wageningen University for analysing my soil samples.

List of abbreviations

ACT – African Conservation Tillage

ADM – Above ground dry matter

AWC – Available water content

CA – Conservation Agriculture

DAP – Days after planting

DD – Dry days

ET – Evapo-transpiration

LAI – Leaf area Index

LER – Land equivalent ratio

MD – Minor drought

RA – Rainfall amount

SBD – Soil bulk density

WUE – Water Use Efficiency

1 Introduction

Low crop productivity of rain-fed crops in the semi-arid agricultural regions in Zimbabwe is a cause of major concern for both farmers and researchers. Combinations of factors which include climatic and edaphic factors are responsible for increasing yield risks while overall yields may be relatively low (Mupangwa, *et al*, 2012). Rainfall is the only source of water in semi-arid rain-fed agriculture and seasonal rainfall amounts are being extremely variable in terms of total amount, actual distribution and intensity which all can limit crop yield (St. Clair and Lynch, 2010). Often long dry spells characterize the rainy season resulting in total crop failure in the worst situations. Rainfall scarcity effects are often aggravated by poor inherent soil fertility and lack of access to inputs prevailing in local smallholder farming systems (SIWI, 2001). Improved soil management including use of different tillage techniques and mulching may facilitate more effective use of limited rainfall while also reducing the impacts of intensive rainfall events (Dixit, *et al*, 2010). This can provide room for the design of ecologically-sound and more resilient cropping systems which also translates to increased crop productivity per unit of land and reduced production risks. Mixed cropping systems through use of intercrops, which are common in some parts of Africa and Latin America (Francis and Adipala, 1994), is an example of a viable alternative for existing mono-cropping systems. In this context, mixed cropping are being characterized by two or more crops being grown in close proximity and via complementarities; such design may result in increased productivity and resilience of the cropping system (Vandemeer, 1989).

The strength of intercrops compared to mono crops lay in their ability to more effectively capture production resources (e.g. light, water and nutrients) and convert them more efficiently into dry matter thereby improving crop yields per unit land area and/or time (Walker and Ogindo, 2003, Fukai and Tranbeth, 1993). Thus intercrops offer an option to ecologically intensify crop production in an effort to improve yields while also minimizing yield risk through crop diversification. This is very important for Zimbabwean smallholder farmers in the wake of declining access to crop land due to continuous soil degradation which has resulted in abandonment of some fields (Nezomba *et. al*, 2008). Intercrops also reduce the agronomic risk of total crop failure via enhanced weed suppression, reduced pests and disease incidences while also providing opportunity for soil fertility improvement. Most of the advantages of intercrop-based systems are mainly due to micro-climate modification which promotes more productive utilisation of limiting resources compared to mono crops (Hulugalle and Ezumah, 1991; Mukhala, 1998; Morris and Garrity, 1993; Baldy and Stigter, 1997).

However, competition for limiting production resources between crops is a potential setback in intercrops (Wiley, 1979). This is quite common under ‘additive’ intercropping arrangement in which

a component crop is added to another crop whose plant density is the same as in mono stand. In rain-fed semi-arid agriculture, where water tends to be severely limiting crop growth, use of intercrops might also cause severe yield reduction of one or more of the cropping system components (Ogindo and Walker, 2005). This perceived risk may be the reason why intercrop-based cropping systems are not commonly used in rain-fed smallholder agriculture in Zimbabwe. However, there are also cases where intercropping benefits are being observed as is illustrated by farmers practicing 'patchy' intercropping. In this case, maize (staple crop) is being grown as the dominant crop with isolated patches of other secondary crops like cowpea, beans, and pumpkins at very low plant densities. Yield of secondary crops, though often very low, is regarded as bonus. On the other hand, implementation of appropriate soil water conservation practices may provide opportunities for smallholder farmers to pursue intercrop-based systems that may be more productive. In this context, modification of tillage and mulching techniques can play a pivotal role when systems are designed such that they can improve soil water capture and retention. This may afford farmers to capitalize on tillage techniques in areas with erratic rainfall, thereby reducing the adverse effects of competition for water between crop components in intercrop-based farming systems.

Tillage is a very important operation in crop production that ensures an optimal seedbed for crop establishment as well as providing effective weed control which both govern initial crop establishment, growth and final yield (Miriti *et al* 2012). There are different tillage methods that are being used or promoted in Zimbabwean smallholder farming system. These can be categorized into two broad groups namely; conventional and conservation tillage. Conventional tillage is a common farmer practice in Zimbabwe. It involves ploughing the whole field using an ox / donkey-drawn plough followed by preparing planting furrows. Conservation tillage may involve manually digging planting basins using a hand hoe or mechanically by opening rip lines using a ripper tine attached to the beam of an ox / donkey-drawn mouldboard plough. Reduced tillage is commonly promoted by international and local governmental and non-governmental organisations under the auspices of African Conservation Tillage (ACT) network that is championing increased use of Conservation Agriculture (CA) throughout Africa. According to Erenstein, (2002), use of crop residue cover (mulch) of at least 30% upon crop emergence qualifies a tillage system to be regarded as conservation tillage. The use of mulching in conservation agriculture enhances soil water capture and retention through enhanced infiltration and suppressed surface evaporation water losses (Erenstein, 2003). Furthermore the mulch may also suppress weeds especially if the mulch thickness is being increased.

Conservation tillage is promoted as a farming practice which ultimately aims to improve and stabilize yields in a more sustainable way (Thierfelder and Wall, 2009). Despite some documented success stories of this farming practice, its adoption by smallholder farmers in Africa is very (s)low. Paltry 0.4 % of the 106 million hectares that is reported to be under CA worldwide is contributed by Africa (Kassam *et. al*, 2009). It is even claimed by the same paper by Kassam *et. al*, (2009) that the majority

of farmers who practice CA in Africa are mainly large commercial farmers mainly in South Africa. According to Kent *et. al*, (2001) weed pressure is one of the main hindrances for smallholders farmers to practice CA. Thus weed pressure under conservation tillage may increase thereby potentially increasing labour requirements and /or dependence on herbicides (Giller, et al, 2009) hence most smallholder farmers prefer the use of conventional ploughing. Many other issues have also been brought forward in contributing to the low adoption of CA by smallholder farmers. These include limited availability of crop residue that may be used as mulching material due to competing alternative uses (Erenstein, 2002).

Soil cover by crop residue under reduced tillage systems is an integral component in CA according to Erenstein, (2002). Applying plant residue cover in conventional tillage systems is not commonly used as a strategy for improving productivity. Therefore this study was undertaken with the objective to compare two tillage systems (reduced and conventional) with or without mulch on the productivity of maize-cowpea cropping system under rain-fed semi-arid smallholder farming system in Zimbabwe. The main focus was on how these contrasting tillage methods interact with mulching effect in terms of water capture and utilization in intercropping and mono-cropping system of maize and cowpea. The main research question was formulated as “how do different tillage systems (reduced vs standard) in combination with mulching techniques (mulch vs bare soil) affect different maize-cowpea crop systems in terms of crop yield and water use efficiency?” Specifically, the study looked at how soil moisture content was affected by tillage and mulching techniques and how did this impacted LAI development, biomass accumulation grain yield and WUE. This was done in order to verify “if there is a synergistic interaction among tillage method, mulching and cropping system on crop yields under rain-fed conditions?” Based on these research questions we hypothesized that conventional tillage system, which is a common farmer practice, when combined with mulching conserves soil moisture more effectively compared to corresponding reduced tillage system. In this manner it may support maize-cowpea intercropping as a more efficient and productive cropping system compared to sole stands of the two crops.

2 Materials and Methods

2.1 Experimental sites

On-farm rain-fed field experiments were conducted during the 2013/14 season in Dendenyore and Ushe wards of Wedza district (18° 41' S and 31°42' E) in the eastern part of Zimbabwe (Fig 2.1). Wedza district falls in the agro-ecological region II, which corresponds to an annual rainfall range of 450mm to 850mm. However, the district also has some isolated areas like the Ushe ward which tend to be drier (typical of agro-ecological region III). Thus conducting the study at two sites meant to test how the combinations of treatments under study would perform under drier and wetter conditions. The rainy season typically stretches from November to March. The soils in Wedza are mostly sandy with a clay and organic carbon content of less than 10% and 2%, respectively (Table 2.1). The prevailing soils have low inherent soil fertility levels and are classified as lixisols according to WRB, (1998). All experimental fields used were previously under maize cultivation.

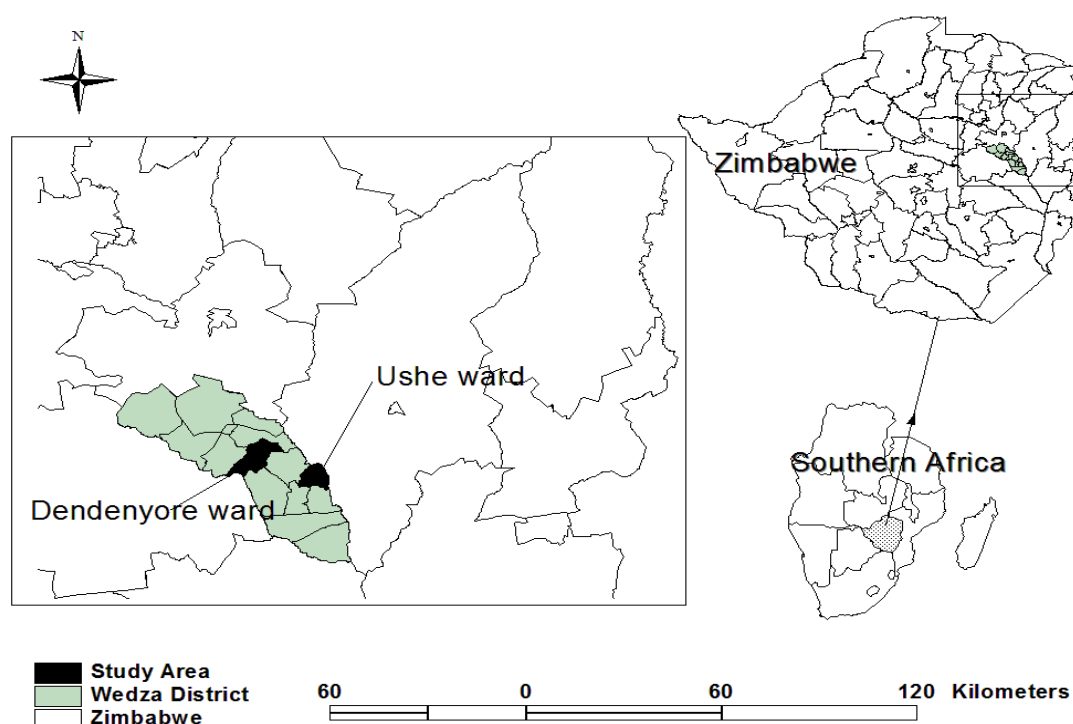


Fig. 2.1. Overview map showing the location of the Wedza district (Dendenyore and Ushe wards) where the on-farm field experiments were conducted

Table 2.1. Selected top soil (0-30cm) characteristics at the two experimental sites.

Soil parameter	Dendenyore	Ushe
pH	5.3	5.4
Total N %	0.02	0.02
SOM %	1.5	1.0
% sand	90.4	91.3
% clay	8.2	7.4
% silt	1.4	1.3

2.2 Experimental design and layout

The experimental treatments were arranged in a split-split plot design with tillage (reduced and conventional) being the main plot; cropping system (maize mono-crop, cowpea mono-crop and maize-cowpea intercrop) as the sub-plot while mulching (bare soil vs. natural mulch) was the sub-sub plot. Each treatment was replicated three times using a Randomised complete block design (RCBD) as shown in the field layout in Appendix 1. Total plot size was 6 x 7 meters with each plot containing 8 rows of plants. To avoid border effects, the first and last row in each plot and the first and last meter of each plant row were not included in any of the measurements. All sites had the same treatments and an outline of treatments is shown in Table 2.2

Table 2.2 Outline of treatment codes along with tillage, crop arrangement, and soil cover design treatments.

Treatment no.	Treatment code	Tillage	Cropping system	Mulching
1	RTMB	Reduced tillage	Maize	Bare
2	RTCB	Reduced tillage	Cowpea	Bare
3	RTIB	Reduced tillage	Intercrop	Bare
4	RTMM	Reduced tillage	Maize	Mulched
5	RTCM	Reduced tillage	Cowpea	Mulched
6	RTIM	Reduced tillage	Intercrop	Mulched
7	CTMB	Conventional tillage	Maize	Bare
8	CTCB	Conventional tillage	Cowpea	Bare
9	CTIB	Conventional tillage	Intercrop	Bare
10	CTMM	Conventional tillage	Maize	Mulched
11	CTCM	Conventional tillage	Cowpea	Mulched
12	CTIM	Conventional tillage	Intercrop	Mulched

2.3 Tillage treatments

- **Reduced tillage:** under this tillage system, rip lines were opened using a ripper tine attached to the beam of an ordinary ox-drawn mouldboard plough. The rip lines were about 15cm deep and the inter spacing of furrows was 75 cm. Planting was done in the rip lines. Weeding was done manually using a hand hoe.
- **Conventional tillage:** under this system, the whole plot was ploughed using an ordinary ox-drawn plough which ploughed to a depth of about 15cm. This was followed by opening planting furrows. This is a common tillage practice by local smallholder farmers in Zimbabwe. Weeding was also done manually by hand hoeing.

2.4 Mulching treatment

- **Bare:** no soil cover was applied to the soil surface
- **Mulched:** Upon the emergency of the crop, approximately 2 tonnes per hectare of common thatching grass (*Hyparrhenia hirta*) plant residue was applied. This amount translated to approximately 30% soil cover and therefore can be considered to comply with CA standards (Erenstein, (2002).

2.5 Cropping treatment

The local early maturing hybrid varieties of maize (SC513) and cowpea (CBC2) were used as test crops. On average the varieties take 120 and 90 days to reach maturity for maize and cowpea respectively. The varieties were purchased from local seed houses and are commonly used by the local smallholder farmers. The two crops were sown in plots measuring 7 m by 6 m. Maize was sown at the spacing of 0.75 m (inter row) by 0.3 m (intra row) in both sole stands and intercrop treatments translating to a plant population of about 44 000 plants ha⁻¹. Cowpea in both sole stands and intercrop was sown at 0.75 m (inter row) by 0.2 m (intra row) with two seeds per station resulting in a targeted plant population of 130 000 plants ha⁻¹. Maize was planted in mid-December and cowpea was planted two weeks later. For the intercrop, maize and cowpea were planted in alternating rows. Typical rates for fertiliser application were used with all the treatments receiving equal amounts of compound D basal fertiliser at 165 kg ha⁻¹ which translated to 11 kg ha⁻¹ N, 10 kg ha⁻¹ P and 10 kg ha⁻¹ K. Top dressing included application of Ammonium nitrate (AN) fertiliser at 69 kg ha⁻¹ (translating to about 26 kg ha⁻¹ N) in two applications at week 4 and 7 after planting to all the plots including maize while mono-cropped cowpea plots did not receive any top dressing. Plots were weeded on 14 and 40 and 60 DAP in Dendenyore whereas the corresponding values were 17 and 54 and 70 DAP for Ushe. Plots were harvested on 24th and 25th April at Dendenyore and Ushe, respectively. This translated to total crop growth duration of 130 and 115 days for maize and cowpea respectively.

2.6 Measurements

Measurements were taken at 4, 8, 12 and 16 weeks after planting (WAP) for maize and 2, 6, 10 and 14 WAP for cowpea. These sampling times corresponds to initial growth, canopy closure, initial tasseling and grain fill stage for maize and to initial vegetative growth, canopy closure, initial flowering and physiological maturity, for cowpea.

a) Soil bulk density and soil water content

The soil bulk density and soil water content were measured at 4-week intervals throughout the experimentation period. Soil water content was measured gravimetrically by collecting two soil samples in the net plot for the top soil (0 – 30 cm) using a stainless steel ring with an internal diameter of 50mm, a height of 4 cm, and a volume of 79.55 cm³. Soil samples were then oven-dried at 105°C for 48 hours to determine the gravimetric water content and soil bulk density using the method outlined by Anderson and Ingram, (1993). The gravimetric water content was converted to the volumetric soil water content using actual soil bulk density values. The soil water content in millimetres (mm) was calculated as the product of volumetric water content and soil depth (thickness from which the soil sample was taken). Available soil water content was calculated as the difference in soil water held by the soil between the field capacity and the lower limit of soil water content (e.g. permanent wilting point). Field capacity was determined through flooding the soil and allowing it to

drain overnight. The lower limit, according to Miriti *et. al*, (2012) was assumed to be the amount of soil during the driest month of the year (in this case the soil moisture content in September)

b) *Leaf area index (LAI)*

Leaf area index (LAI) was determined manually at peak leaf growth just before flowering (i.e. 9 and 7 weeks after planting for maize and cowpea respectively). For maize, a non-destructive method was used in which individual leaf area was calculated as a product of length, width and a constant value which was 0.75 according to Mokhtarpour *et. al*, (2010). For cowpea 30 leaves of different sizes were destructively harvested and the leaf blades of these leaves were traced on paper to later calibrate leaf area upon getting an access to LA meter. The dry weight of the traced leaf blades was determined as well as the weight of all the leaf blades of the sampled plants. This enabled calibration and calculated values were used to determine leaf area based on the actual number of plants per plot.

c) *Crop and land productivity*

Crop biomass was taken every 4 weeks from the inside plots which were 5.5 m by 4.5 m. Two row sections of 1 m long were sampled in each sub-plot and plants were cut at the soil surface. For the final crop harvesting maize cobs and cowpea pods were separated from the stover. A subsample was then taken for moisture correction through drying the samples at 70°C for 48 hours. The grain weight was measured at approximately 12.5% moisture content. Local prevailing grain prices of maize and cowpea were used to come up with the monetary grain value. Maize price was assumed to be \$0.35 per kg while cowpea this value was \$0.50 per kg. Net grain values in monetary terms were obtained by subtracting total costs which included labour, fertilisers and seed input associated with the different treatments from the grain value obtained.

Overall land productivity was determined using the land equivalent ratio (LER) equation described by Willey, (1985). The LER was computed as:

$$\frac{\text{Intercropped maize yield}}{\text{Maize sole stand yield}} + \frac{\text{Intercropped cowpea yield}}{\text{Cowpea sole stand yield}} \quad \text{(Equation 1)}$$

Thus the LER refers to the comparative land area under mono crop stands required to produce yields comparable to those for an intercrop. A LER value larger than one implies improved land utilization efficiency of intercrop-based systems compared to sole stands. On the other hand a value below one is indicative of total yield reduction for the intercrop-based systems.

d) *Crop water use*

Rainfall was measured at each site using a standard rain gauge which was mounted 1 m above the ground in an uncropped open space. No supplemental irrigation was applied to the crop and based on the methods outlined by Miriti *et. al*, (2012) it was assumed that drainage and run off were negligible.

Crop above-ground dry matter Water Use Efficiency (WUE) was calculated as the ratio of biomass and rainfall amount received by the crop corrected for the change in soil water content within the root zone (Miriti *et. al*, 2012). Therefore WUE (expressed as kg DM mm⁻¹) was calculated as shown in Equation 2.

$$\text{WUE} = \frac{\text{ADM}}{\text{ET}} = \frac{\text{ADM}}{(\text{RA} - \Delta\text{S})} \quad \text{(Equation 2)}$$

Where: ADM = above ground dry matter, ET = water loss by evapotranspiration, RA = rainfall amount received by crops, ΔS= the change in the amount of soil water within the root zone during the cropping season.

For the intercrop, WUE was calculated on the basis of total dry matter of maize and cowpea. In the case of yield- and monetary-based WUE values, ADM in Equation 2 was replaced by the total grain yield and product of grain yield and income, respectively.

e) *Analysis of soil organic content*

The percentage of accumulated soil organic matter (SOM) following different treatments was determined by collecting soil samples from the top 15 cm of the soil. The samples were only taken from 1st and 2nd blocks due to the time constraint. The samples were air-dried and brought to The Netherlands. Mr Halm Hennie of Farming Systems Ecology helped with the laboratory analysis. Basically the soil samples were ground to pass a 2 mm sieve with visible plant materials discarded from the soil sample. The SOM content was estimated in organic carbon form based on Walkley-Black acid digestion method according to Anderson and Domsch, (1989).

f) *Statistical analysis*

Analysis of variance was conducted to assess the effects of tillage and mulching on the maize-cowpea cropping systems on soil bulk density, water capture, LAI, productivity and accumulated SOM using Genstat (Genstat 15, VSN International, Hemel Hemstead, UK). In order to determine the level of significance amongst means for different treatment combinations, a probability range of 0.001 to 0.05 was used.

3. Results

3.1 Rainfall

The amount of rainfall at the two sites during the experimental period was similar with Dendenyore and Ushe receiving 642mm and 650 mm, respectively (Fig. 3.1a). The cumulative rainfall amount received during the first 120 days after planting was also rather similar for both sites as depicted in Fig 3.1 b.

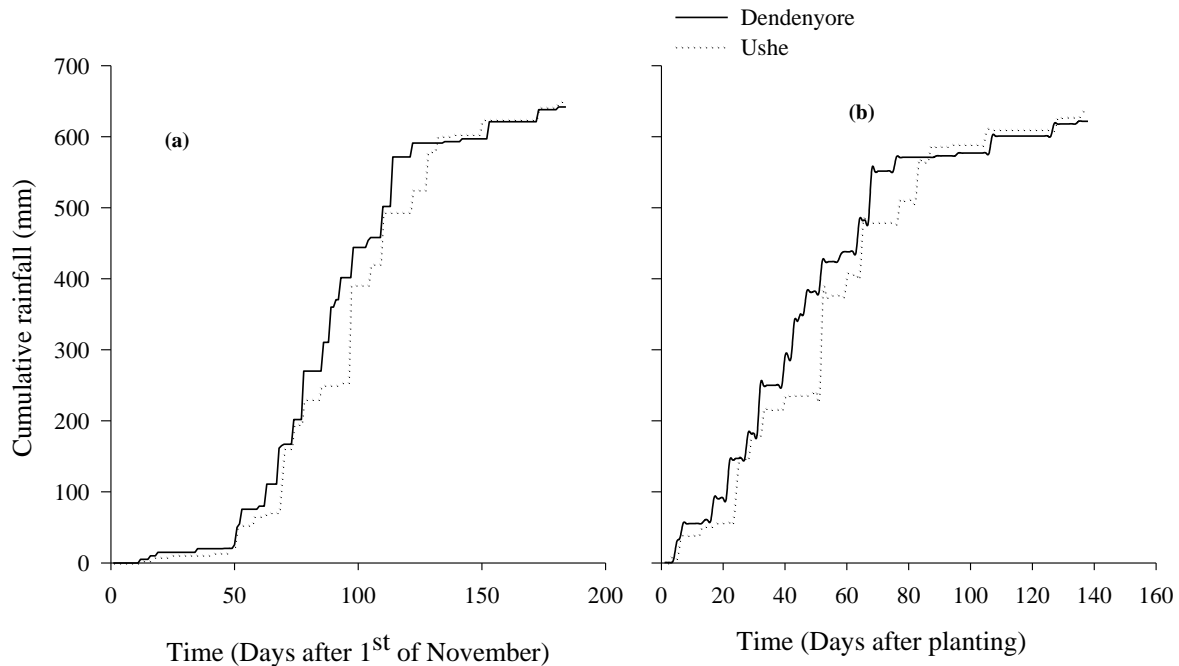


Fig.3.1. Cumulative rainfall distribution as a function of days after 1st of November (a) and days after planting (b) at the Dendenyore and Ushe field sites during the experimental period.

The rainfall distribution pattern at the two study sites was also similar as depicted in Fig. 3.2. The frequency of rain amount distributions days [<0.5 (dry days), 0.5-5mm, 5-10 mm, 10-20 mm, 20-40 mm, 40-80 mm, > 80 mm] along with the frequency of minor drought events (> 7 days with < 1 mm of cumulative rainfall) during the first 120 days after planting was slightly different with Dendenyore receiving lower number of dry days (DD) than Ushe as shown in Fig. 3.3. The season during the study was generally favourable at all sites as there were no major dry spells which occurred. Only minor drought conditions occurred at all sites but these were not observed to adversely affect crop growth.

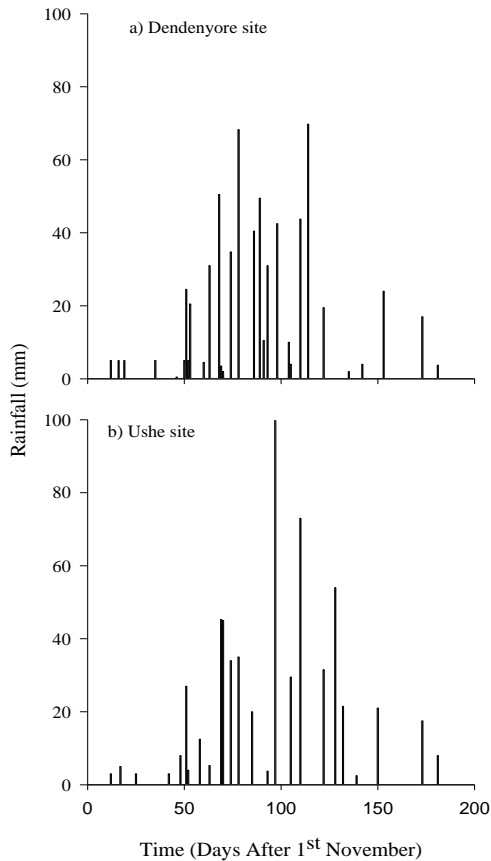


Fig. 3.2. Daily rainfall distribution for Dendenyore (a) and Ushe (b)

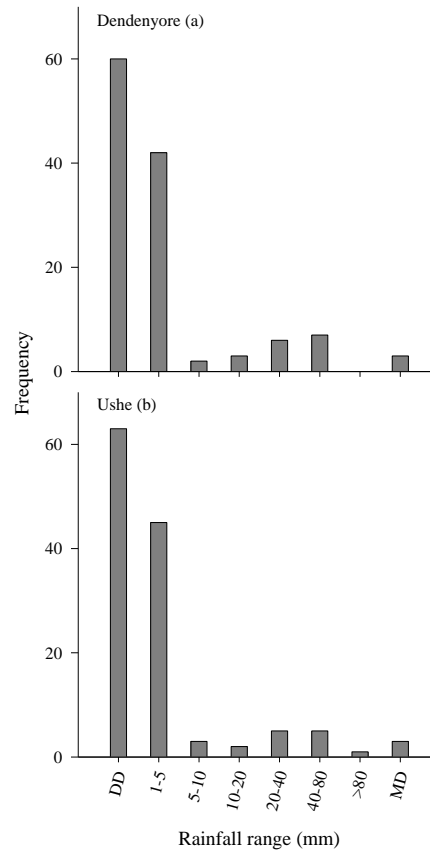


Fig. 3.3. Frequency rainfall range, dry days (DD) (days which receive < 0.5mm rainfall) and minor drought events (MD) (> 7 days with < 1 mm of cumulative rainfall) distribution during the first 120 days after planting for Dendenyore (a) and Ushe (b). The total numbers of dry days (DD) (< 0.05) were 60 and 63 for Dendenyore and Ushe, respectively.

3.2 Soil bulk density

The values for the soil bulk density (SBD) of the 0-30 cm soil layer at the Dendenyore and Ushe site at the different sampling times are shown in Table 3.1. In general it appears that SBD values were similar at both sites. For reduced tillage, SBD tended to decrease over time whereas for conventional tillage the reverse occurred (Fig. 3.4). The rate of decrease of SBD with time under reduced tillage was greater at Ushe compared to that at Dendenyore as shown by the slope of fitted regression line; -0.0103 and -0.0045 for Ushe and Dendenyore respectively (Fig 3.4 a and c). On the other hand the rate of increase in SBD under conventional tillage was more pronounced at Dendenyore (slope = 0.0069) compared to Ushe (slope = 0.0056) (Fig 3.4 b and d). Overall values for reduced tillage were 10% higher compared to conventional tillage right after planting, whereas at the end of the growing season SBD values were either similar (Dendenyore) or even slightly lower (Ushe) for reduced tillage. This implies that in the absence of ploughing, the inherent soil physical structure and overall soil porosity tended to improve over time

whereas ploughed soil got compacted during the cropping cycles. In terms of mulching, use of mulching tended to decrease SBD values at both sites with this effect being most pronounced during the initial growth stage of the plants. With respect to crop effects, at Dendenyore overall SBD values were similar across cropping systems, whereas at Ushe initial values were lowest for the intercrop while at the end values were lowest for maize and highest for cowpea. More specific trends and interaction effects for both sites will be discussed in more detail in the next section.

Table.3.1. Interactive effects of tillage (Red. = reduced and Conv. = conventional), mulching (bare and mulched) and cropping system (Intercropping, Maize only, and Cowpea only) on soil bulk density at 4, 8, 12 and 16 weeks after planting (WAP) of maize (corresponding to 2, 6, 10 and 14 WAP for Cowpea) at Dendenyore and Ushe.

Factor	Soil bulk density (g cm ⁻³)							
	Dendenyore				Ushe			
	4WAP	8WAP	12WAP	16WAP	4WAP	8WAP	12WAP	16WAP
<i>Tillage (T)</i>								
Red.	1.145b	1.099	1.067	1.095	1.157b	1.133b	1.117	1.092a
Conv.	1.039a	1.078	1.068	1.135	1.048a	1.061a	1.106	1.107b
Significance	*	ns	ns	ns	***	**	ns	*
<i>Cropping (C)</i>								
Maize	1.067	1.076	1.068	1.124	1.115b	1.106b	1.104a	1.070a
Cowpea	1.099	1.087	1.073	1.106	1.116b	1.104b	1.119b	1.121c
Intercrop	1.110	1.103	1.066	1.114	1.076a	1.079a	1.112a	1.108b
Significance	ns	ns	ns	ns	***	***	*	***
<i>Mulch (M)</i>								
Bare	1.113b	1.099	1.088b	1.117	1.114b	1.101b	1.117b	1.103b
Mulched	1.072a	1.078	1.050a	1.113	1.091a	1.092a	1.106a	1.097a
Significance	*	ns	*	ns	***	***	*	**
<i>Interactions</i>								
T x C	ns	**	ns	ns	**	***	ns	***
T x M	ns	ns	ns	ns	***	***	ns	***
C x M	**	ns	ns	ns	***	***	ns	***
T x C x M	ns	ns	ns	ns	***	***	ns	***

¹. WAP = weeks after planting (maize/cowpea)

². *, **, *** and ns = P values <0.05, <0.01, 0.001 and not significant, respectively

³. means with the same letter are not significantly different

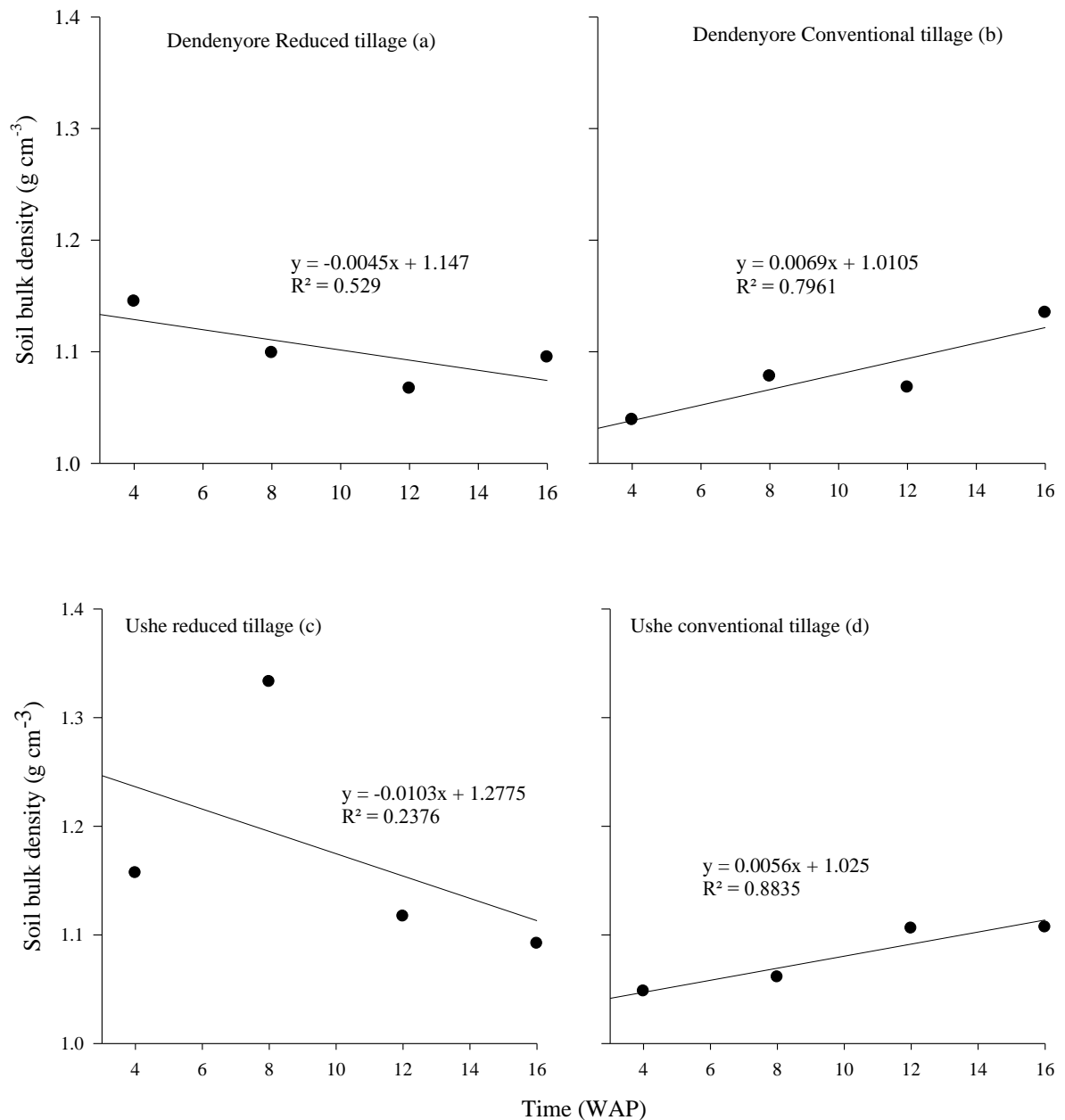


Fig. 3.4. General soil bulk density trends for the different tillage systems (reduced and conventional) at Dendenyore (**a**= reduced tillage and **b**= conventional tillage) and Ushe (**c**= reduced tillage and **d**= conventional tillage) during the experimental period.

Dendenyore site

The three-way interaction among Tillage (T) x Cropping systems (C) and Mulching (M) on SBD was not significant at Dendenyore, while at 4 WAP (initial vegetative crop growth) and 8 WAP (canopy closure) the C x M and T x C interactions were significant (Table 3.1). For completeness all the interactions among tillage, cropping and mulching systems for the Dendenyore, are depicted in Fig. 3.5 **a- c**. In terms of the two-way interaction of cropping system and mulching (C x M) was significant at the initial vegetative growth of the crops (i.e. 4WAP) with bare mono crops (maize and cowpea only) having significantly

higher SBD compared to corresponding mulched treatments (Fig.3.5 **a** and **b**). This is explained by the lack of soil surface shield against raindrop action. This was further aggravated by the fact that the plants were still small. However, for intercropping system at the same stage of crop growth, there were no significant differences between mulched and bare treatments suggesting higher plant population other than mulching was more responsible for the differences in SBD values between sole stands and intercropping systems. For the tillage and cropping interaction (T x C), which happened during the initial tasselling and flowering stage for maize and cowpea respectively (i.e. 8WAP) mulched-conventional tillage had the lowest numeric SBD values. However, these values were not significantly different to conventional tillage system especially in maize sole stand.

In terms of the overall main effects, tillage method tended to have an effect on SBD during the first period with the reduced tillage treatment having significantly higher SBD compared to the conventional tillage plots (Table.3.1). While over time these differences dissipated. In terms of cropping systems, there were no significant or consistent differences throughout the experimentation period (Table.3.1). With respect to mulching, in the absence of mulch, initial SBD tended to be 5% higher compared to mulched treatments with these differences gradually becoming smaller over time which may be related to the mulch material gradually being decomposed.

Ushe site

At Ushe the three-way interaction occurred during all the stages of the crop growth except at initial tasselling and flowering for maize and cowpea respectively (12 WAP). In all the crop growth stages in which interaction occurred, conventional tillage especially under mulched treatments resulted in significantly least SBD values in all cropping systems. For completeness, all the interactions among tillage, cropping and mulching systems for the Dendenyore, are depicted in Fig. 3.5 **d- f**. Interaction effects were most pronounced for the bare reduced tillage plots in all cropping systems which started having the highest SBD but with values declining steeply over time. On the other hand the mulched-conventional tillage started with the least SBD values which gradually increased over time perhaps due to the mulching material which was being decomposed. In terms of main effects, reduced tillage always had relatively high SBD values except during initial tasselling / flowering (i.e. at 12 WAP) where there was no significant difference between the two tillage systems. For the cropping system, intercropping had always the lowest SBD values than the mono crops except at grain / pod filling stage (i.e. 16 WAP) where it had the second least value after that of maize mono crop. For the mulching effect, mulched surface had always significantly lower values of SBD compared to the corresponding treatments in which the soil surface was left bare.

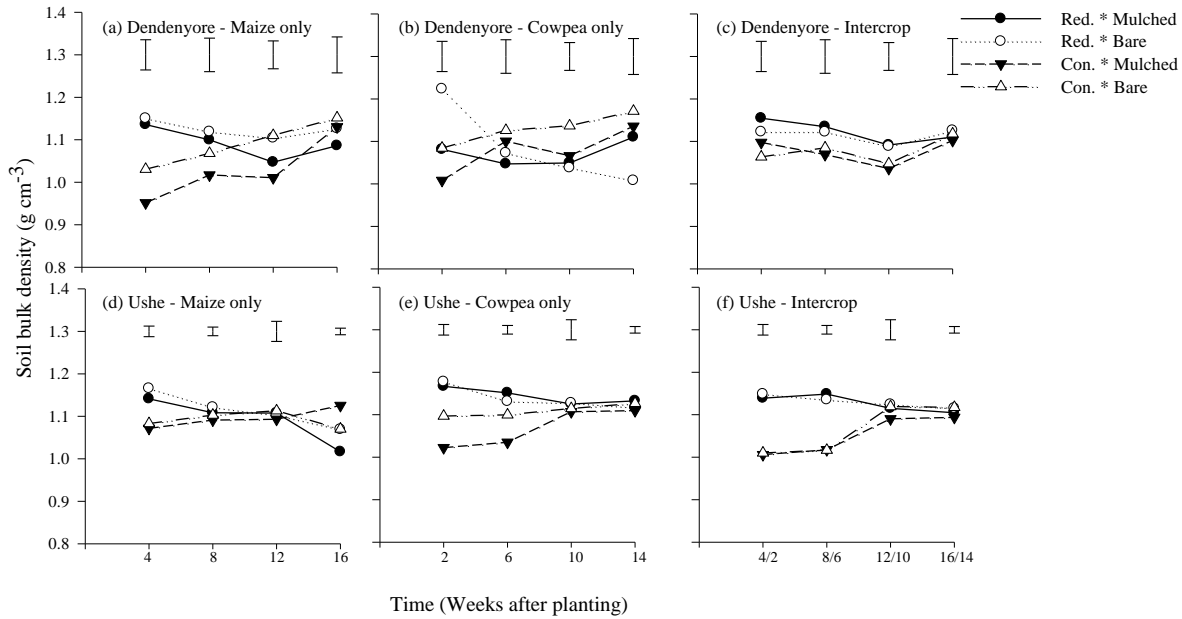


Fig 3.5. Interactive effects of tillage (Red. = reduced vs Conv. = conventional), mulching (bare vs mulched) and cropping system (Intercropping, Maize mono-crop, and Cowpea mono-crop) on soil bulk density in the 0–30 cm soil layer over time for Dendenyore (a-c) and Ushe (d-e). Error bars represent LSD_{0.05}.

3.3 Soil available water content

The values for the available water content (AWC) in mm at the Dendenyore and Ushe sites at the different sampling times are shown in Table 3.2. Values of AWC during initial crop growth were relatively low especially in Ushe (Fig 3.6). This can be attributed to low amount of rainfall received as well as soil surface evaporation since the plants did not yet have closed canopies. Before initial flowering (WAP 6-8), overall AWC values were fairly high, which was related to incidence of repeated heavy rainfall events (> 20-40 mm) at both sites. Over time values gradually decreased due to decreased rainfall events as well as increased utilisation by the crop.

There were some notable differences between the two sites with regard to the AWC. For the first half of the season, there was no significant difference between the reduced tillage and conventional tillage at Dendenyore. Significant differences only emerged during the second half with reduced tillage at tasselling / flowering (i.e. at 12 WAP) having significantly more soil available water than the conventional tillage before the reverse occurred at grain filling / pod filling (16 WAP). At Ushe, the reverse scenario of Dendenyore occurred in which significant differences between the two tillage systems occurred only during the first half with conventional tillage starting with significantly more water than the reduced tillage during the initial vegetative growth of the crops (i.e. at 4 WAP) and the reverse was true at canopy closure

(i.e. at 8 WAP). With regard to crop effect, generally the intercropping system had always the lowest AWC values compared to the mono crops (Dendenyore). It appears that increased plant population density per plot under intercropping resulted in more water extraction than mono crops. At the Ushe site, this pattern was not clear as intercropping system at times would have the highest AWC value though differences were not significantly compared to either one of the mono crops. In terms of mulching, a mulched soil surface generally resulted in higher AWC and this is explained by suppression of surface evaporation as the mulch cover shield the soil from sun heat. Lower values in mulched plots compared to corresponding bare surface plots implies that soil water was utilised more by the crop under mulched systems compared to bare systems. Specific trends and interaction effects for both sites will be discussed in more detail in the next section.

Table.3.2. Interactive effects of tillage (Red. = reduced and Conv. = conventional), mulching (bare and mulched) and cropping system (Intercropping, Maize only, and Cowpea only) on soil available water content at 4, 8, 12 and 16 weeks after planting (WAP) of maize (corresponding to 2, 6, 10 and 14 WAP for Cowpea) at Dendenyore and Ushe.

Factor	Soil available water content (mm)							
	Dendenyore				Ushe			
	4WAP	8WAP	12WAP	16WAP	4WAP	8WAP	12WAP	16WAP
Tillage (T)								
Red.	12.56	29.06	13.27b	10.05a	4.91b	26.79a	15.96a	18.06
Conv.	12.68	28.65	11.90a	10.58b	4.28a	35.51b	17.31	17.51
significance	ns	ns	***	**	**	**	ns	ns
Cropping (C)								
Maize	14.74c	31.49b	12.89b	12.18c	5.20c	30.65	15.79	17.39
Cowpea	13.11b	30.73b	14.00c	10.13b	3.78a	31.33	17.85	18.54
Intercrop	10.01a	24.35a	10.87a	8.65a	4.80b	31.47	16.25	17.44
significance	***	***	***	***	***	ns	ns	ns
Mulch (M)								
Bare	12.80b	28.03a	12.69	9.96a	4.61	28.58a	16.85	17.70
Mulched	12.44a	29.69b	12.48	10.67b	4.58	33.72b	16.41	17.88
significance	**	***	ns	***	ns	***	ns	ns
Interactions								
T x C	***	*	***	**	***	**	*	ns
T x M	ns	ns	***	*	***	*	ns	ns
C x M	*	***	***	ns	*	***	ns	**
T x C x M	***	***	ns	ns	***	ns	ns	ns

¹. WAP = weeks after planting (maize/cowpea)

². *, **, *** and ns = P values <0.05, <0.01, 0.001 and not significant respectively

3. Means with the same letter are not significantly different

Dendenyore site

The three-way interaction of tillage, mulch and cropping system for AWC was significant during the initial vegetative crop growth and canopy closure (i.e. at 4 and 8 WAP) (Table 3.2) with mulched-conventional tillage having greater AWC values in intercrop and cowpea cropping systems (Fig 3.6 b and c). For maize mono crop during the same period the mulched-conventional tillage had lower AWC values (Fig 3.6 a). At initial tasselling / flowering (i.e. at 12 WAP) and grain / pod filling (i.e.16 WAP) the interaction between tillage and crop as well as that between crop and mulch were significant (Table 3.2).

Intercrop under mulched-conventional tillage had significantly higher AWC values at the initial flowering / tasselling stage of the two crops (critical stage which drastically affect yield under water limiting conditions) before being similar to other combinations of cropping system, mulch and tillage at grain / pod filling (Fig. 3.6 c). For maize and cowpea the reduced bare treatment combination had significantly higher AWC at the initial flowering / tasselling (Fig 3.6 a and b). At grain / pod filling cowpea under bare reduced tillage recorded the lowest AWC values (Fig 3.6 b).

In terms of main effects, tillage affected AWC only during the last two periods of data collection with conventional tillage having less available soil water compared to the reduced tillage system at the initial flowering / tasselling crop stage (Table.3.2). However, at grain / pod filling, this was reversed as reduced tillage had significantly higher AWC than the conventional tillage. For cropping system effects, the intercrop system had the lowest AWC values throughout the season compared to sole stands (Table.3.2). Mulching effects showed only significant differences during the initial vegetative crop growth and at canopy closure. During the initial vegetative crop growth, the bare treatment had significantly higher AWC values than the corresponding mulched treatment. However, this trend was reversed at canopy closure (Table.3.2) with mulching recording significantly more AWC than the bare soil surface.

Ushe site

Interaction of tillage, mulch and cropping was only significant during the initial vegetative growth stage of the crops (Table.3.2) with the mulched-conventional tillage having the lowest AWC values under intercropping system (Fig 3.6 f). For the sole stands, maize and cowpea values were similar during this period (Fig 3.6 d and e). The interaction of crop and mulch was significant at canopy closure (Table.3.2) with mulching showing greater AWC values compared to bare surface in all cropping systems (Fig.3.4 d, e and f). The interaction of tillage and mulch was also significant at canopy closure (Table.3.2), with mulched conventional tillage having higher AWC values in all cropping systems (Fig 3.6 d, e and f). The bare-reduced tillage had the lowest AWC values (Fig 3.6 d, e and f). The difference in soil AWC between the two tillage systems was only significant during initial crop growth and canopy closure with reduced tillage starting (i.e. during initial vegetative crop growth) having relatively high AWC values compared to conventional system but at canopy closure, the reverse was true (Table.3.2). In terms of cropping system effects, at initial vegetative growth maize mono crop had the highest values followed by intercrop systems while cowpea had relatively low AWC values (Table.3.2). For the mulching treatment, significant differences were only noted at canopy closure with mulched treatments recording more water than bare treatments (Table.3.2).

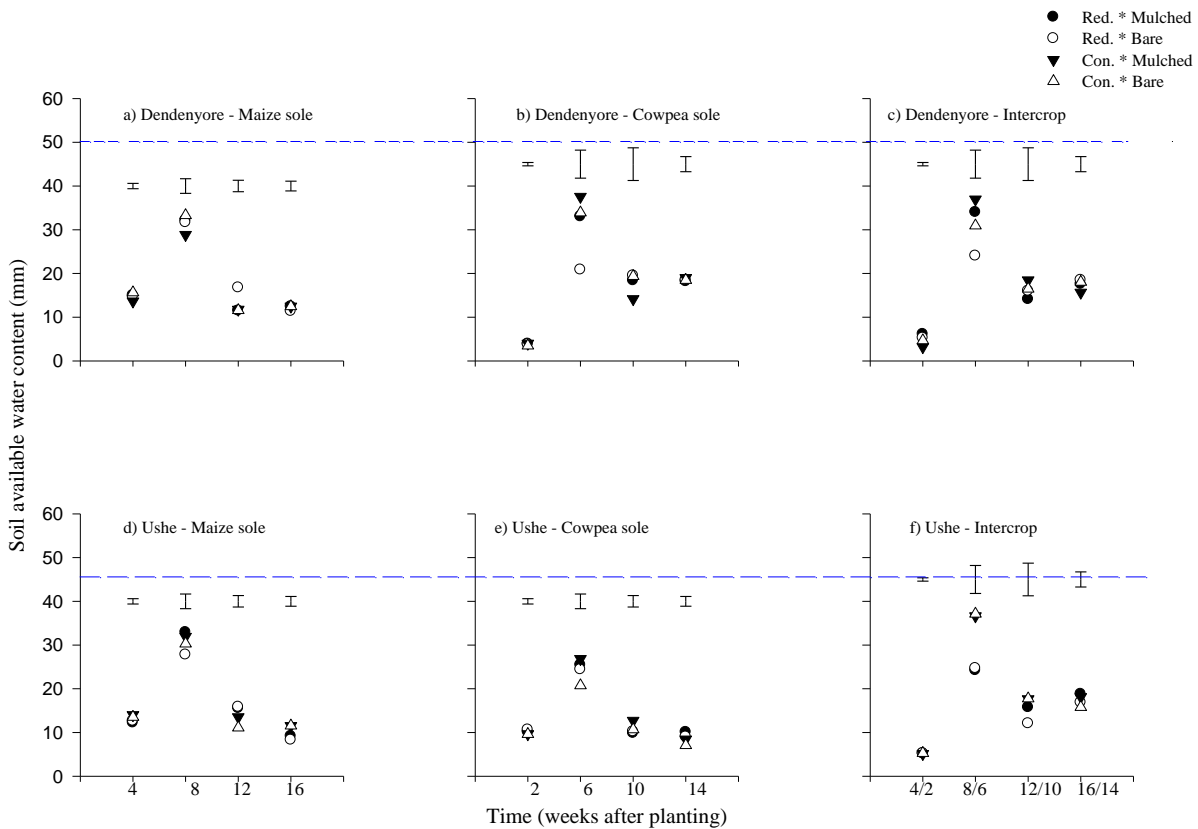


Fig 3.6. Interactive effects of tillage (Red. = reduced and Conv. = conventional), cropping system (Intercropping, Maize only, and Cowpea only) and mulching (bare and mulched) on soil available soil water content (0-30cm depth) over time at Dendenyore (a-c) and Ushe (d-e). Error bars represent $LSD_{0.05}$. The line dotted refers to maximum soil AWC values for the 0 – 30cm soil layer.

3.4 Leaf area index (LAI)

The LAI values at peak leaf crop growth (corresponding to 9 and 7 WAP for maize and cowpea, respectively) at Dendenyore and Ushe are shown in Table 3.3. In general, the conventional tillage had significantly higher LAI values compared to reduced tillage at both sites but at Ushe the difference between the two tillage systems was most pronounced. In terms of cropping systems effects, intercropping system had significantly greater LAI values compared to corresponding mono crops at both sites. The LAI values of the mono crops were almost twice as high as those for intercropping system at both sites which may be related to the higher total plant population in intercropping systems. In Dendenyore, cowpea had higher LAI values compared to maize, whereas at Ushe the reverse was true. Regarding the effects of mulching, there were noted differences between the two sites. At Dendenyore there was no significant difference between bare and mulched treatments whereas at Ushe the difference was strong with mulching achieving more LAI than leaving the soil surface bare. More specific and interaction effects for both sites will be discussed in more detail in the next section.

Table 3.3. Interactive effects of tillage (Red. = reduced and Conv. = conventional), mulching (bare and mulched) and cropping system (Intercropping, Maize only, and Cowpea only) on LAI at 9/7 WAP (maize/cowpea respectively) at Dendenyore and Ushe.

Factor	LAI (m ² m ⁻²)	
	Dendenyore	Ushe
Tillage (T)		
Reduced	1.786a	0.865a
Conventional	2.034b	1.672b
significance	*	***
Cropping (C)		
Maize sole	1.295a	1.070b
Cowpea sole	1.400a	0.742a
Intercrop	3.035c	1.994c
significance	**	***
Mulching (M)		
Bare	1.888	1.155a
Mulched	1.932	1.382b
significance	ns	***
Interactions		
T x C	*	ns
T x M	**	ns
C x M	**	*
T x C x M	*	ns

¹. WAP = weeks after planting

². *, **, *** and ns = P values <0.05, <0.01, 0.001 and not significant respectively

³. Means with the same letter are not significantly different

Dendenyore site

The three-way interaction among tillage, mulching and cropping system factor was significant in terms of LAI values (Table.3.3). Intercropping system under the mulched-conventional tillage had the highest LAI value being about 3.6 m² m⁻² followed by cowpea under reduced tillage for which values were not affected by mulching (Fig.3.7a). Conventional tillage achieved greater LAI values compared to reduced tillage in intercropping system (Fig. 3.7a). For cowpea the reverse was true and in maize sole stand there was no significant difference between the two tillage systems. Regarding main effects of cropping system, intercropping had the highest LAI values followed by cowpea (especially under reduced tillage) while maize had relatively low LAI values (Table.3.3). For the mulching main effect, there was no significant difference between mulched and bare treatments though the former had slightly higher numeric values than the later (Table.3.3).

Ushe site

The only interaction which occurred was between crop and mulch ((Table.3.3) with the mulching treatments in all cropping systems achieving higher LAI values than the corresponding bare treatment. In terms of main effects, conventional tillage showed higher LAI values than corresponding reduced tillage plots (Table 3.3). Regarding cropping system effects, there was a strong significant difference among the cropping systems with intercropping achieving the highest LAI values followed by maize and lastly

cowpea (Fig.3.7b). The highest LAI was recorded in intercropping under conventional tillage. However, LAI values were similar for the mulched and bare conventional tillage in the intercrop (Fig.3.5b). The difference between mulching and bare was only significant in maize with the mulched treatments having higher LAI values than corresponding bare treatments in all tillage systems.

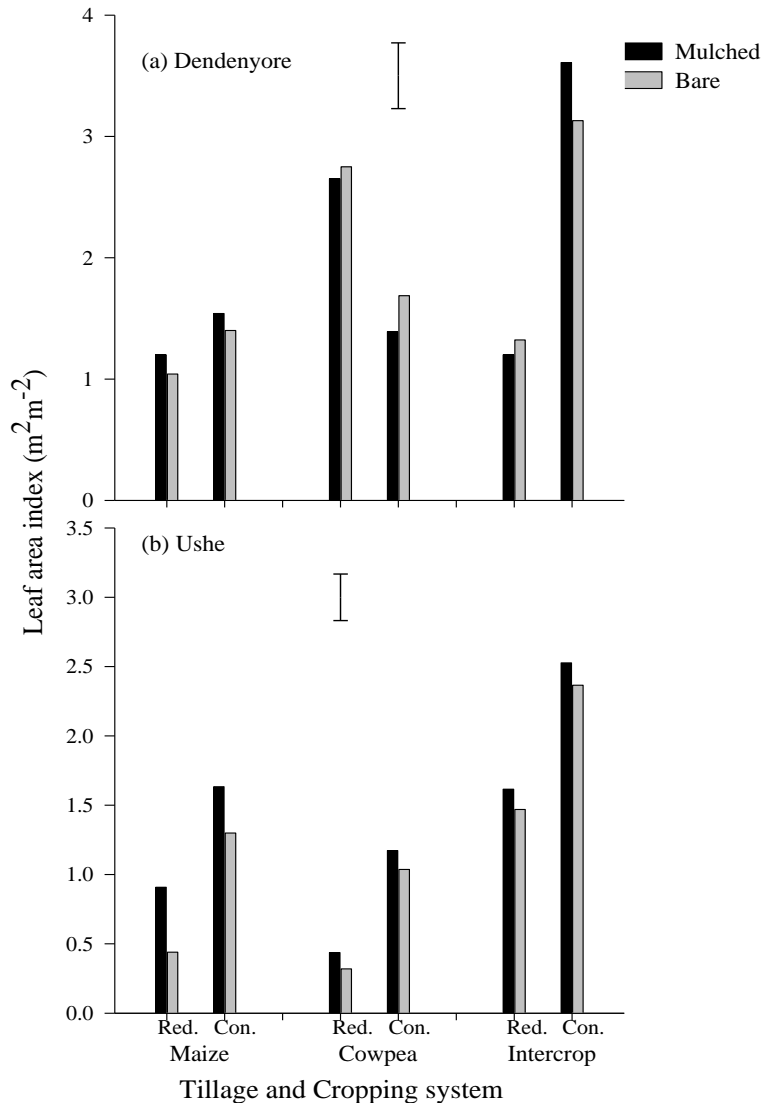


Fig.3.7. Interactive effects of tillage (Red. = reduced and Conv. = conventional), cropping system (Intercropping, Maize only, and Cowpea only) and mulching (bare and mulched) on LAI at 9 WAP maize (corresponding to 7 WAP cowpea) at Dendenyore (a) and Ushe (b). Error bars represent $LSD_{0.05}$.

3.5 Above-ground dry matter accumulation

The values for above-ground dry matter accumulation (ADMA or biomass) and corresponding WUE (WUE_{DM}) values at Dendenyore and Ushe at different sampling times are shown in Table 3.4 and Table 3.5, respectively. The general trend for WUE (Fig. 3.7) followed biomass (Fig. 3.6). Biomass accumulation between the two sites was also similar though the one for the actual values were relatively

low at Ushe, especially for the reduced tillage treatments. Initially there was no significant difference between the two tillage systems. However, with time the differences began to become more articulated with the conventional tillage always being more productive than the reduced tillage at both sites (Dendenyore and Ushe). In terms of the cropping system effects, intercropping always had the highest ADMA values, followed by maize mono crop and lastly the cowpea mono crop. This was true for both sites. Regarding the mulching effect, mulched treatments were significantly more productive than corresponding bare treatment at both sites. However, initial difference between mulched and bare were insignificant at both sites as well as at initial tasselling / flowering stage (i.e. 12 WAP) of the crops at Dendenyore site only. More specific trends and interaction effects for both sites will be discussed in more detail in the next section.

Table 3.4. Interactive effects of tillage (Red. = reduced and Conv. = conventional), mulching (bare and mulched) and cropping system (Intercropping, Maize only, and Cowpea only) on above ground dry biomass at 4, 8, 12 and 16 weeks after planting (WAP) of maize (corresponding to 2, 6, 10 and 14 WAP for Cowpea) at Dendenyore and Ushe.

Factor	Above ground dry matter accumulation (Kg ha ⁻¹)							
	Dendenyore				Ushe			
	4WAP	8WAP	12WAP	16WAP	4WAP	8WAP	12WAP	16WAP
Tillage (T)								
Red.	125.4	812a	2887a	4458a	75.6	633.1a	1280a	1696a
Conv.	126.0	1233b	4499b	6103b	80.0	870.2b	3538b	4970b
significance	ns	*	**	**	ns	***	***	***
Cropping (C)								
Maize	131.1b	970b	3351b	4511b	84.4b	505.9b	2384b	3137b
Cowpea	35.5a	473a	2180a	3430a	26.7a	196.8a	1518a	1953a
Intercrop	210.5c	1625c	5548c	7900c	122.4c	1552.1c	3326c	4910c
significance	***	***	***	***	***	***	***	***
Mulch (M)								
Bare	124.5	940a	3612	4976a	80.0	724.7a	2095a	2989a
Mulched	126.9	1105b	3774	5585b	75.7	778.6b	2723b	3678b
significance	ns	***	ns	***	ns	***	***	***
Interactions								
T x C	ns	ns	***	***	ns	***	***	***
T x M	**	*	**	***	ns	ns	*	**
C x M	**	*	**	***	ns	***	ns	**
T x C x M	**	*	ns	***	ns	***	*	ns

¹. WAP = weeks after planting (maize/cowpea)

². *, **, *** and ns = P values <0.05, <0.01, 0.001 and not significant respectively

3. Means with the same letter are not significantly different

Table 3.5. Influence of tillage (reduced and conventional) and mulching (bare and mulched) on above-ground dry matter accumulation based water use efficiency (WUE_{DM}) values at 4, 8, 12 and 16 weeks after planting (WAP) of maize (corresponding to 2, 6, 10 and 14 WAP for Cowpea) at Dendenyore and Ushe.

Factor	WUE_{DM} (Kg/mm)							
	Dendenyore				Ushe			
	4/2WAP	8/6WAP	12/10WAP	16/14WAP	4/2WAP	8/6WAP	12/10WAP	16/14WAP
Tillage (T)								
Red.	1.26	2.17a	4.99a	7.055a	1.155	2.804a	2.51a	2.686a
Conv.	1.27	3.30b	7.77b	9.660b	1.207	3.976b	6.97b	7.861b
Significance	ns	*	**	**	ns	***	***	***
Cropping (C)								
Maize	1.36b	2.62b	5.79b	7.17b	1.287b	2.276b	4.69b	4.962b
Cowpea	0.36a	1.28a	3.78a	5.43a	0.399a	0.889a	2.99a	3.095a
Intercrop	2.08c	4.31c	9.57c	12.48c	1.857c	7.001c	6.54c	7.762c
Significance	***	***	***	***	***	***	***	***
Mulch (M)								
Bare	1.25a	2.51a	6.238	7.87a	1.215	3.22a	4.12a	2.334a
Mulched	1.28a	2.96b	6.521	8.84b	1.147	3.55b	5.36b	3.038b
Significance	ns	***	ns	***	ns	***	***	***
Interactions								
T x C	ns	ns	***	***	ns	***	***	***
T x M	**	*	**	***	ns	ns	*	*
C x M	**	*	**	***	ns	***	ns	*
T x C x M	**	*	ns	***	ns	***	*	Ns

1. WAP = weeks after planting (maize/cowpea)

2. *, **, *** and ns = P values <0.05, <0.01, 0.001 and not significant respectively

3. Means with the same letter are not significantly different

Dendenyore

The three-way interaction of tillage, cropping system and mulching effect on ADMA and WUE_{DM} values was significant at all times except during the maize tasselling and cowpea flowering stage (i.e. 12 WAP) (Tables 3.4). Observed trends for biomass mirrored those for WUE_{DM} as illustrated by Fig. 3.8 and Fig. 3.9, which is to be expected since biomass forms the base for WUE_{DM} calculations. Intercrop combined with mulched-conventional tillage performed always significantly better compared to all other combinations (Fig 3.8 and Fig 3.9). This treatment combination was followed by intercrop under bare-conventional tillage system. Intercrop under reduced tillage whether with or without mulch achieved significantly lower values compared to corresponding intercrop under conventional tillage system. Mulched-conventional tillage was also the best combination for maize mono cropping system (Fig.3.8 a and Fig. 3.9 a). For cowpea mono cropping system, there was no significant difference among all the combinations of tillage and mulch throughout the study period (Fig.3.8 b and Fig. 3.9 b). In terms of tillage effects, after the initial vegetative growth of crops (i.e. 4 WAP) tillage main effects on the above ground dry biomass and WUE_{DM} were significant throughout the entire growing season with the conventional tillage being more productive than the reduced tillage. With respect to cropping system effects, pronounced differences occurred with intercropping system being more productive than mono cropping systems while mono-cropped cowpea showed the lowest biomass production. Regarding

mulching, starting at canopy closure, mulched treatments had significantly greater biomass and WUE_{DM} values compared to corresponding bare treatments. The significance difference between mulching and leaving the surface bare disappeared at initial tasselling / flowering stage of the crops (i.e. 12 WAP) before re-emerging again at grain / pod filling (i.e. 16 WAP).

Ushe site

Similar to the Dendenyore site, WUE_{DM} trends (Fig. 3.9 **d**, **e** and **f**) followed those for biomass production (Fig. 3.8 **d**, **e** and **f**). Significant three way interactions of tillage, mulching and cropping systems occurred at canopy closure and initial tasselling / flowering (Table 3.4 and Table 3.5). Mulched-conventional tillage was the most productive combination in all the cropping systems though during the grain / pod filling (i.e. at 16 WAP); there was no significant difference between mulched and bare conventional tillage system under cowpea mono crop (Fig. 3.8 **e** and Fig. 3.9 **e**). Overall, intercropping under mulched-conventional tillage was always the most superior combination (Fig. 3.8 and Fig. 3.9). Regarding the main effects of tillage, conventional tillage outperformed reduced tillage in all the cropping systems though initially (i.e. at 4 WAP) differences were not yet significant (Fig.3.8 and Fig. 3.9). In terms of cropping system effects, intercropping system achieved higher productivities and efficiencies compared to sole stands followed by maize while cowpea systems scored lowest. With respect to mulching, initially it had no significant effect (Table 3.4 and 3.5). The effect only started to manifest at canopy closure till the end with the mulched treatments being always more productive than corresponding bare treatments.

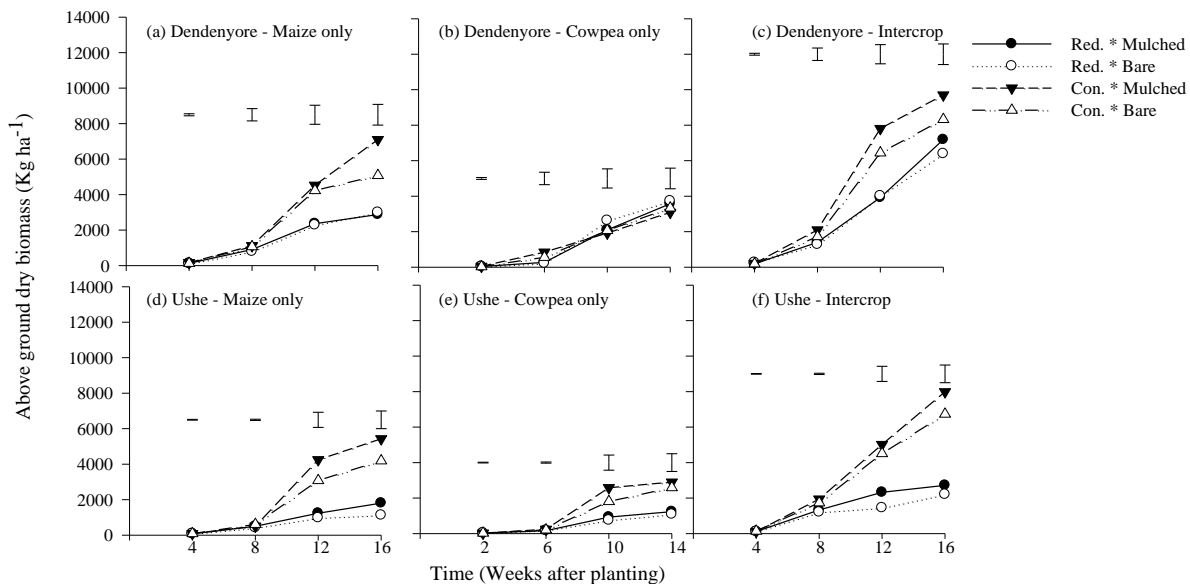


Fig. 3.8. Interactive effects of tillage (Red. = reduced and Conv. = conventional), cropping system (Intercropping, Maize only, and Cowpea only) and mulching (bare and mulched) on total above-ground dry biomass at Dendenyore (**a-c**) and Ushe (**d-e**) sites. Error bars represent $LSD_{0.05}$.

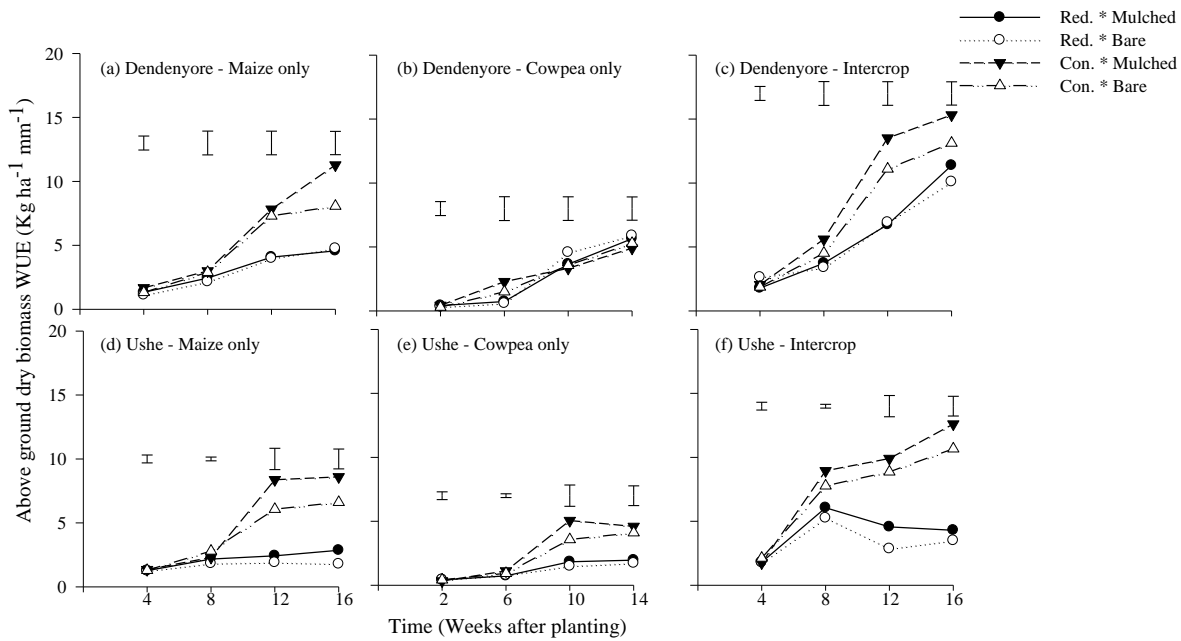


Fig. 3.9. Total above ground dry matter WUE over time for Dendenyore (a-c) and Ushe (d-e) as affected by tillage (Red. = reduced and Conv. = conventional), cropping system (Intercropping, Maize only, and Cowpea only) and mulching (bare and mulched). Error bars represent $LSD_{0.05}$

3.6 Grain yield

The values for the grain yield expressed as total grain yield per hectare, and grain yield-based Water Use Efficiencies (WUE_{YLD}), total income generated (if the grain was sold) and the economic (WUE_{ECON}) at the Dendenyore and Ushe sites at harvesting are presented in Table 3.6. At both sites there were significant differences between the two tillage systems with regard to all the measured components (total grain yield, WUE_{YLD} , income, and WUE_{ECON}). The conventional tillage system outperformed the reduced tillage for all the components at both sites. In terms of income as well as WUE_{ECON} , conventional tillage system achieved about 70 % and 160 % higher values compared to corresponding reduced tillage systems at the Dendenyore and Ushe sites, respectively. At the Ushe site there was an enormous challenge to manage the weeds under reduced tillage which is reflected by more pronounced yield difference between the two tillage systems. This resulted in net loss in terms of income and WUE_{ECON} in all cropping systems under reduced tillage system (Fig. 3.12b and 3.13b). At Dendenyore a net loss in terms of income and WUE_{ECON} happened only in cowpea mono crop but surprisingly under conventional tillage (Fig. 3.12a and Fig. 3.13a). Net loss of cowpea can be explained ‘wetly’ conditions due to conventional tillage which compromised grain yield since cowpea favours drier conditions.

In terms of the cropping system effects, the results showed that grain yield and WUE_{YLD} was highest under intercropping systems. Thus positive interaction between crops in intercropping systems appears to be

more apparent than competition for resources like water, although water stress may not have been very articulated this year. Intercropping was followed by maize mono crop and lastly cowpea except at Ushe where there was hardly any significant difference between maize and cowpea with regards to WUE_{ECON} . With regards to mulching effects, mulched treatments resulted in significantly greater measured grain yields and WUE components than the corresponding bare treatments (Dendenyore). Thus at Ushe site there was no significant difference between mulching and leaving the soil surface bare. More specific trends and interaction effects for both sites will be discussed in more detail in the next section.

Table 3.6. Interactive influence of tillage (reduced and conventional) and mulching (bare and mulched) on grain yield ($Kg ha^{-1}$), grain yield-based WUE_{YLD} ($Kg mm^{-1}$), net grain value (\$) and economic-based WUE_{ECON} ($\$ mm^{-1}$) for Dendenyore and Ushe.

Factor	Dendenyore				Ushe			
	Yield $Kg ha^{-1}$	WUE_{YLD} $Kg mm^{-1}$	Net Income value(\$)	WUE_{ECON} $\$ mm^{-1}$	Yield $Kg ha^{-1}$	WUE_{YLD} $Kg mm^{-1}$	Net Income value(\$)	WUE_{ECON} $\$ mm^{-1}$
Tillage (T)								
Red.	1076a	1.703a	114.6a	0.181a	398a	0.629a	-260.0a	0.282a
Conv.	1992b	3.152b	396.0b	0.626b	2082b	3.293b	460.0b	1.301b
significance	*	*	*	*	**	**	**	**
Cropping (C)								
Maize	1556 b	2.472b	202.0b	0.321b	732b	1.158b	-140.0a	0.410a
Cowpea	548a	0.867a	-12.6a	-0.020a	555a	0.880a	-68.0b	0.446a
Intercrop	2498c	3.944c	576.5c	0.910c	2432c	3.845c	508.0c	1.519b
significance	***	***	***	***	***	***	***	***
Mulch (M)								
Bare	1417a	2.241a	212.1a	0.335a	1218	1.928	88.0	0.771
Mulched	1651b	2.614b	298.5b	0.472b	1262	1.994	113.0	0.813
significance	***	***	***	***	ns	ns	ns	ns
Interactions								
T x C	***	***	***	***	***	***	***	***
T x M	***	***	***	***	ns	ns	*	*
C x M	***	***	***	***	ns	ns	ns	ns
T x C x M	*	*	*	*	*	*	*	*

¹. WAP = weeks after planting

². *, **, *** and ns = P values <0.05, <0.01, 0.001 and not significant respectively

³. Means with the same letter are not significantly different.

Dendenyore site

There was an interaction among tillage, mulch and cropping system with regard to total grain produced per hectare, grain WUE, total grain value and economic WUE (Table 3.6). Conventional tillage was significantly more productive than reduced tillage especially in intercropping and maize mono cropping systems. The intercropping cropping system was the most lucrative especially under mulched-conventional tillage though there was no significant difference with the corresponding intercrop under bare conventional tillage (Fig. 3.10 a, Fig. 3.11 a, Fig. 3.12a and Fig. 3.13a). However, under the reduced tillage system, there was no significant difference between mulching vs leaving the soil surface bare in all the mono crops. Significant differences between bare and mulched soil treatments were only significant

under maize mono crop under conventional tillage system with the mulched outperforming non-mulched treatments. For cowpea, all combinations of tillage and mulching had similar grain yields productivity. Overall, in terms of main effects, conventional tillage achieved significantly higher yields compared to reduced tillage while regarding cropping systems, intercropping system was significantly more lucrative than mono cropping. With respect to mulching, its use resulted in higher yields, income and efficiencies compared to bare treatments.

Ushe site

The interaction among tillage, mulch and cropping system was significant with regards to total grain produced per hectare, WUE_{YLD} , total grain value and WUE_{ECON} (Table 3.6). The intercrop under conventional tillage was superior for all indices. There was no significant difference between the bare and mulched conventional tillage in intercrop though the former was more productive than the later (Fig. 3.10 **b**, Fig. 3.11 **b**, Fig. 3.12**b** and Fig. 3.13**b**). Conventional tillage generally performed better than the reduced tillage in intercrop and maize mono crop. However, for cowpea there was no significant difference between the two tillage systems. Maize productivity under reduced tillage (either mulched or bare) was lowest and it was similar to that of cowpea while mulching had no significant effect in all grain productivity components. In terms of net economic benefit and efficiencies, reduced tillage even achieved negative values in all cropping systems whether under mulch or with the surface left bare (Fig. 3.12 and 3.13)

At this site there was a serious challenge of weeds (predominantly *Cynodon dactylon* (L)) in the reduced tillage system. The weed infestation level was such that casual labour hired to do hand-hoe weeding were initially not willing to weed the plots stating it was too strenuous and a difficult task. An agreement was reached upon offering double the amount offered in conventional tillage system. Crop yields were negatively impacted by weeds as persuading the farmer to carry out the weeding operation took a while and delayed the actual weeding by two weeks.

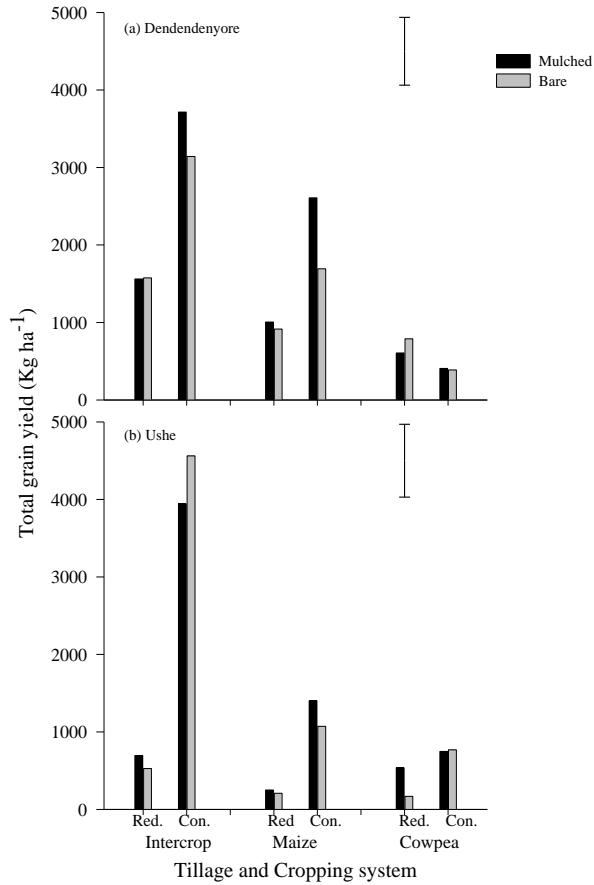


Fig. 3.10. Interactive effects of tillage (Red. = reduced and Conv. = conventional), cropping system (Intercropping, Maize only, and Cowpea only) and mulching (bare and mulched) on total grain yield at Dendenyore (a) and Ushe (b) sites. Error bars represent LSD_{0.05}.

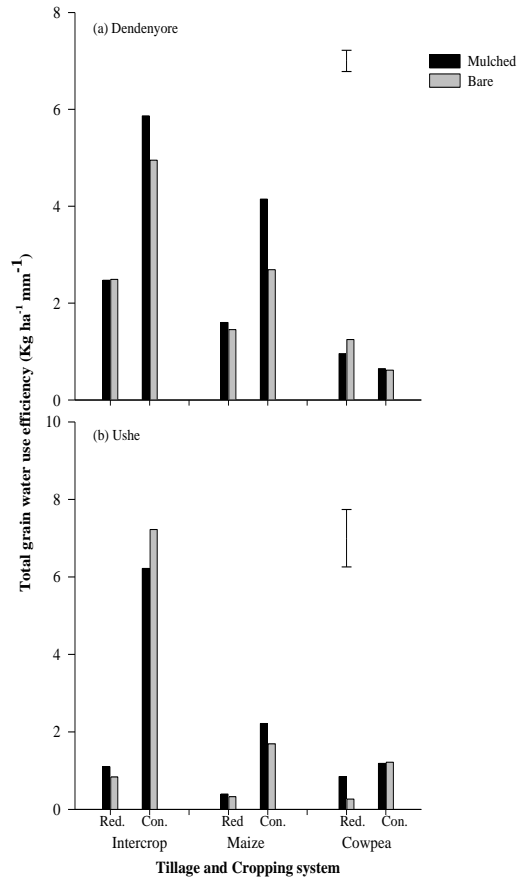


Fig. 3.11. Interactive effects of tillage (Red. = reduced and Conv. = conventional), cropping system (Intercropping, Maize only, and Cowpea only) and mulching (bare and mulched) on total grain WUE at Dendenyore (a) and Ushe (b) sites. Error bars represent LSD_{0.05}.

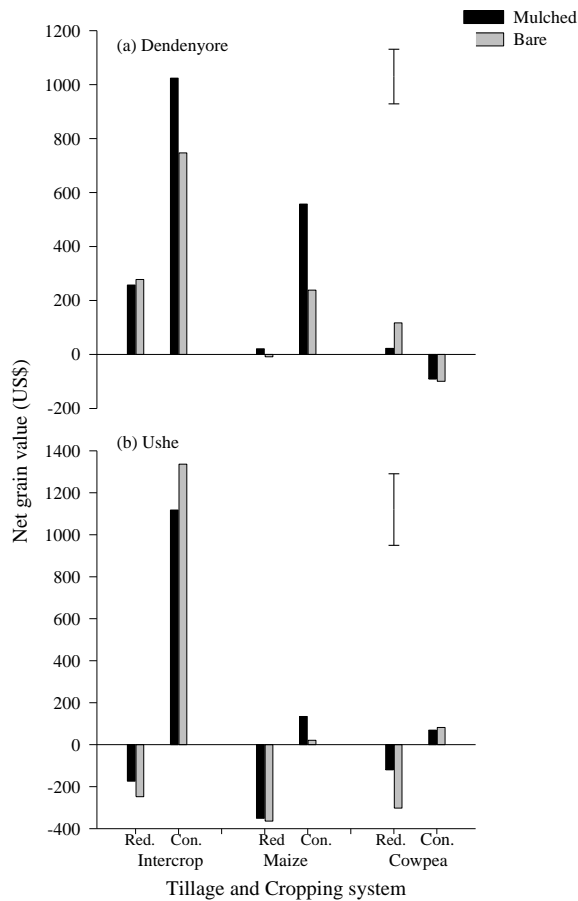


Fig. 3.12. Interactive effects of tillage (Red. = reduced and Conv. = conventional), cropping system (Intercropping, Maize only, and Cowpea only) and mulching (bare and mulched) on net grain value at Dendenyore (a) and Ushe (b) sites. Error bars represent $LSD_{0.05}$.

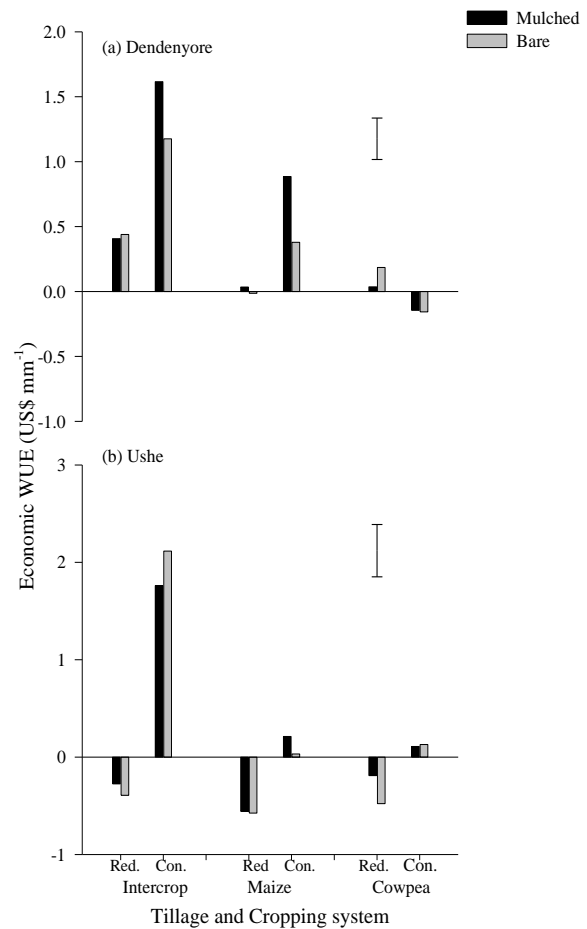


Fig. 3.13. Interactive effects of tillage (Red. = reduced and Conv. = conventional), cropping system (Intercropping, Maize only, and Cowpea only) and mulching (bare and mulched) economic WUE at Dendenyore (a) and Ushe (b) sites. Error bars represent $LSD_{0.05}$.

3.7 Land productivity

To check if the intercropping of maize and cowpea under the contrasting tillage and mulching treatments had increased land productivity, LER which is the relative area under mono crops required to produce the intercrop yield was computed using Equation 1 and the results are shown in Table 3.7. All the LER values were generally greater than one as shown (Table 3.7). Intercropping was significantly more productive per unit of land than sole stands under all combinations of tillage and mulch. Bare mulching generally resulted in intercropping being more advantageous than mono cropping in all the tillage systems at all study sites. Mulching, on the other hand, resulted in greater land productivity under reduced tillage system compared to conventional tillage system.

Table 3.7. Land equivalent ratio (LER) values of the intercropping system at the two sites as affected by tillage and mulching treatment.

Tillage	Dendenyore		Ushe	
	Bare	Mulched	Bare	Mulched
Reduced till	2.07 BCa	2.11 BCa	2.96Cb	2.40 Ba
Conventional till	1.81 Ba	1.30 Ab	3.00Cb	1.10 Aa

¹ Means with the same letters are not significantly. Small caps (**a, b**) compares within one tillage system and large caps (**A, B, C**) compares across tillage systems.

3.8 Soil organic matter (SOM) content (%)

The values for the soil organic content percentage are shown in Table 3.8. The differences in treatments were only significant at Ushe site while at Dendenyore there was no significant difference among any of treatment combinations. In general, conventional tillage had higher SOM content values compared to reduced tillage at both sites though this difference was not significant at Dendenyore as highlighted earlier. This can be explained by more removal of top soil in reduced tillage which became more vulnerable after rigorous weeding regimes compared to corresponding conventional tillage. In terms of cropping system main effects, intercropping system had significantly greater SOM values compared to corresponding mono crops (Ushe site). The SOM values of the mono crops (maize sole and cowpea sole) were not significantly different. High numerical SOM values in intercropping systems may be related to the higher total plant population in intercropping systems. Regarding the effects of mulching, again at Dendenyore the difference was not significant though generally mulching resulted in higher SOM values compared to the corresponding bare treatment. At Ushe the difference between the mulched and bare plots was most pronounced with the former having higher SOM content values than the later. The addition of soil surface cover in form of plant residue, which decomposes over time, is a possible explanation of the difference between mulched and bare systems. More specific and interaction effects for both sites will be discussed in more detail in the next section.

Table 3.8. Interactive effects of tillage (Red. = reduced and Conv. = conventional), mulching (bare and mulched) and cropping system (Intercropping, Maize only, and Cowpea only) on SOM content soon after harvesting at Dendenyore and Ushe.

Factor	Soil organic matter content (%)	
	Dendenyore	Ushe
Tillage (T)		
Reduced	1.510	1.032a
Conventional	2.232	1.243b
significance	ns	*
Cropping (C)		
Maize sole	1.694	1.096a
Cowpea sole	1.858	1.141a
Intercrop	2.061	1.176b
significance	ns	*
Mulching (M)		
Bare	1.664	1.063a
Mulched	2.078	1.213b
significance	ns	***
Interactions		
T x C	ns	*
T x M	ns	ns
C x M	ns	ns
T x C x M	ns	*

¹. WAP = weeks after planting

². *, **, *** and ns = P values <0.05, <0.01, 0.001 and not significant respectively

³. Means with the same letter are not significantly different

Dendenyore site

Though there was no significant difference among all the treatments it was interesting to note that generally conventional tillage systems generally resulted in more SOM content than the corresponding reduced tillage system (Fig. 3.14 a). For the cropping system, intercropping had more values of SOM compared to the mono crops. Intercropping was followed by sole cowpea and lastly sole maize. For the mulching main effect, mulched systems generally had higher SOM content values compared to corresponding bare systems under all tillage systems and in all cropping systems except for maize mono crop under conventional tillage system where the values between mulched and bare systems were almost the same (Fig. 3.14 a)

Ushe site

There was a three-way interaction among tillage, mulching and cropping systems (Fig 3.14 b). Conventional tillage systems generally had higher values compared to corresponding reduced tillage systems especially in sole maize and intercrop. Intercropping systems achieved slightly more values than mono crops. For the mulching effects, mulching resulted in more SOM content values than leaving the soil surface bare. This was true in almost all cropping systems under all tillage systems. Overall, intercropping under mulched-conventional tillage was the best combination in terms of SOM

content. This can be explained by high plant population which made the system to be more resilient to the loss of top soil.

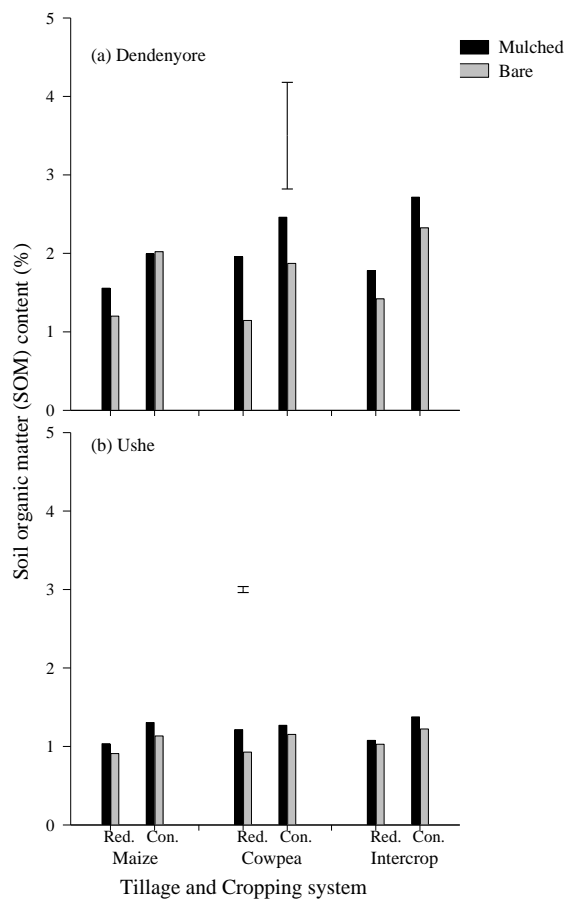


Fig.3.14. Interactive effects of tillage (Red. = reduced and Conv. = conventional), cropping system (Intercropping, Maize only, and Cowpea only) and mulching (bare and mulched) on SOM content (%) after harvesting at Dendenyore **(a)** and Ushe **(b)**. Error bars represent $LSD_{0.05}$.

4. Discussion

4.1 Rainfall

The crop growth results between two sites under study were generally comparable. This could have been due to similar rainfall amount (Fig.3.1) and distribution (Fig. 3.2). The rainfall amount received was close to the annual range of 650 to 850mm typically received at two sites. Absence of a major drought as well as low incidences of minor droughts as depicted in Fig. 3.3 at both study sites made the season more favourable to crop production compared to most previous seasons. This resulted in bumper harvests by most farmers in all the areas. Based on soil moisture data (Fig. 3.6) it appears that rainfall may have been a bit low during initial growth at Ushe while values were more favourable during initial yield formation. However, often the Ushe site is more vulnerable to prolonged dry spells than Dendenyore with total crop failure being a common phenomenon when these long dry spells coincide with the critical stages of the crops like flowering (Prof. Mapfumo, personal communication).

4.2 Tillage and mulching effect

This study generally revealed benefits of combining both conventional tillage and mulching in terms of improved productivity (Fig. 3.10 and 3.11), increased gross income and production efficiencies which allowed reaping full benefits of an maize-cowpea intercrop system (Fig. 3.12 and 3.13). Furthermore the combination, improved soil organic matter content at least in the short term (Fig. 3.14) hence improved soil quality. Overall, the mulched-conventional tillage combination provided the best production techniques to implement mixed cropping system through intercropping. Productivity per unit area was also improved compared to mono cropping. Thus conventional ploughing as a tillage method when combined with mulching through covering the soil with plant residue as soil management option can intensify rain-fed crop production systems. How the conventional tillage system may reinforce mulching techniques will be explained in the paragraphs below.

Tillage as an operation aims to create an optimal seed bed for crop establishment which increases soil porosity as reflected by lower soil bulk density. Total porosity percentage may be defined as $(1 - \text{soil bulk density}/\text{the specific density of the soil matrix material}) * 100$ (Rasmussen, 1999, Brady and Weil, 1999). From this formula it is evident that as the soil bulk density increases the porosity decreases. Moreover, soil bulk density may also be used as a proxy of soil mechanical resistance to root penetration. It was shown that there is an inverse relation between soil bulk density and root growth (Thompson *et al.*, 1987). Thus soil bulk density determines the soil strength and penetrability of the soil by plants as they grow to extract water and nutrients from deep soil layers (Wang *et. al*, 2009). Conventional ploughing in this study resulted in significantly lower initial soil bulk density than reduced tillage through ripping (Table 3.1). This was consistent with findings by Tebrugge and During, (1999). This could have given plants under conventional tillage a head start in terms of roots establishment since roots may move more effectively to explore deeper soil layers through loosened

soil in conventional ploughing compared to reduced tillage system. This gave roots an opportunity to extract water which was not affected by surface evaporation thereby buffering the crops against some adverse effects of minor drought events during the course of the growing season. However, declining of soil bulk density in reduced tillage system with time while under conventional tillage systems it increased (Fig 3.4) provide some evidence that over time reduced tillage systems may also have positive effects on soil porosity and/or structure.

In the context of the current study it should be emphasized that tillage has also an important role to play in weed control. Weeds are serious yield reducing factor in crop production through competing for resources like water with crops and in some cases can be allelopathic (Liebman and Dyck, 1993) Conventional tillage systems can offer a more effective way to control weeds thereby resulting in a more conducive environment for crop growth which over time may translate into improved productivity compared to reduced tillage systems. In reduced tillage systems weeds can be a serious problem and according to Giller *et. al*, (2009) this presents a major hindrance to CA adoption by smallholder farmers as reduced tillage (CA principle) results in more labour demand for weeding. During the course of this study an acute weed pressure was also experienced under the reduced tillage especially at Ushe site with *Cynodon dactylon* (L) grass being a dominant weed species. Double the amount paid in conventional tillage needed to be paid for casual labour to do hand weeding in reduced tillage system. There was also reluctance from casual labour to weed the plots due to high infestation level which greatly increased labour requirements per unit land to be weeded for reduced tillage. This experience reveals the magnitude of the potential problems for effective weed management in CA systems in the absence of chemical weed control. Thus reduced tillage may pose a serious constraint during initial adoptions of reduced tillage practices as integral component of CA (Kent *et. al*, 2001). This illustrates why it may be an enormous challenge to convince smallholder farmers to practice reduced tillage system. If the time requirements for weeding CA-based plots are double this may result in labour conflicts and/or delay in weeding operations as was the case in the current study. The effects of delaying weeding by two weeks as was the case in Ushe greatly contributed towards reduced maize crop productivity as shown in Fig 3.10 **b**.

Covering the soil surface with plant residue defined as mulching played a critical role during the study with regard to enhanced soil water capture and retention especially in conventional tillage systems (Fig. 3.6 **b** and **c**). This reduced the risk of soil water limitations which would otherwise trigger adverse effects of competition between crops for water especially in intercrops. Cowpea being a drought tolerant crop which performs best under drier conditions failed to do well under 'wet' conditions due to the presence of mulch in conventional tillage (Fig. 3.10 **a**). The role of mulching from this study confirms the findings from other researchers like Unger *et. al*, (1991), Hatifield *et al*, (2001) and Erenstein, (2002) who showed that covering the soil with crop residues is a highly effective soil management option to enhance soil water capture and retention. Water capture is

enhanced through improved infiltration as the soil is shielded against raindrop impact which would otherwise compact the soil thereby minimizing infiltration. Suppressed soil surface evaporation through soil cover by plant residue enhances retention and according to Hatfield *et al.*, (2001) soil water evaporation can be reduced by almost 50% when the soil is mulched.

Mulching material used in this study was the common thatching grass and the fact that it gave such excellent results holds promise. It is a natural and renewable resource that may contribute towards addressing the competition of use of mulching material as part of CA technology with feedstuffs in Zimbabwean rain-fed smallholder farming system. Common thatching grass does not have many competing uses like crop residue which is mostly promoted under CA. In contrast, use of crop residue has many competing uses including forage and fuel. Moreover, crop stover yields tend to be low while materials are readily degraded by termites or lost due to grazing by cattle after harvesting. Common thatching grass though also has a critical function in construction as roofing material; its use is currently declining according to my direct observation and talking with local farmers as most families now can afford to buy permanent roofing material in the form of asbestos or iron sheets for their houses.

4.3 Cropping systems and WUE

This study clearly showed that intercropping systems were significantly more productive than mono cropping systems (Fig. 3.8 **c** and **f**, Fig. 3.9 **c** and **f**, Fig. 3.10, Fig. 3.11, Fig. 3.12 and Fig. 3.13). This happened despite the lowest amount of soil available water in intercrops compared to corresponding mono crops especially at Dendenyore site (Table 3.2). So it is evident that even in intercropped systems with relatively high plant populations water limitations appeared to be minor. Moreover, intercrop systems featured the highest biomass production (Table 3.4 and Fig 3.8) and economic yield (Fig. 3.12) suggesting intercropping system as more efficient in utilising soil water than mono crops. Thus the results of this study revealed complementation and synergy between crops in intercropping system being more apparent than competition. The findings of this study were consistent with those of Ogindo and Walker (2005) who found out that additive intercrops have higher water to biomass conversion compared to mono cropping. Thus intercrops may be more productive than mono crops. Improved productivity in intercrops is explained by a modified micro-climatic condition due to improved groundcover (Tranbeth, 1993). Highest LAI in intercropping in this study (Fig. 3.7) confirms this. The improved groundcover is quite beneficial in reducing air circulation thereby lowering surface evaporation (unproductive soil water loss) and promotes productive soil water loss through transpiration (Hulugalle and Ezumah, 1991, Ogindo and Walker, 2005). Furthermore, improved ground cover in intercropping systems improves rain water infiltration as well light interception resulting in high biomass production (Walker and Ogindo, 2003, Fukai and Tranbeth, 1993). Overall, the findings of this study have shown that intercropping may be a good option to intensify crop production especially under mulched-conventional tillage. This allows scarce resources

like water to be captured and utilized to the fullest extent to improve crop productivity per unit area. However, given that there were no severe or prolonged drought events during the current cropping season, potential competition for water may have been relatively low.

4.4 Land productivity

Calculated land equivalent ratios (LER) values greater than one (Table 3.7) are indicative that intercropping system had a beneficial yield advantage compared to mono cropping system (Willey, 1985). The fact that intercropping at all the study sites under contrasting tillage systems and mulching treatments achieved LER value greater than one (Table 3.7) can be explained by the favourable rainfall distribution throughout the season. Thus there were no soil water moisture deficits which could have adversely affected intercropping through competition for water between the two crops.

4.5 Soil organic matter content

It is quite interesting to note that besides maize-cowpea intercropping under mulched-conventional tillage system being the best combination in terms of productivities and efficiencies; it also did provide soil quality benefits by resulting in higher SOM (Fig. 3.14). This benefit can be explained by the fact that mulched-conventional tillage system gave optimal environment for crops to grow in intercropping system thereby yielding more plant biomass which could have reduced the top soil loss through soil erosion. Furthermore, dead leaves and roots from the crop together with the plant residue as mulching material which decomposes with time helped in improving the SOM though this cannot be the most plausible explanation due to the short time period of the study. Thus if it was a long term study, the results would have been in agreement with the findings of Snapp *et.al*, (1998) and Saroa and Lal, (2003) who found out that covering the soil surface with plant residue (mulching) and high plant populations in cereal-legume intercrops increases SOM.

4.6 Effects of CA on crop productivity

This study showed that crop productivity under reduced tillage even when combined with mulching is still significantly lower than conventional ploughing (common farmer tillage practice). This provides evidence that the (s)low uptake of CA among smallholder farmers in Zimbabwe which emphasize the requirement for a reduced tillage and mulching also mirrors technical weaknesses of proposed technology packages. Farmers thus may find themselves in a vicious circle of food insecurity due to low yields hence they may be looking for results which manifest immediately after engaging and investing in a specific technology. Perhaps as suggested by Sidibé, (2005), CA through its reduced tillage system provides long-term yield benefits. However, this study provides initial evidence that by combining mulching with conventional ploughing in Zimbabwe, both yield, WUE and land productivity may be greatly improved in a short-term. Moreover, use of maize-cowpea intercrop based systems may further contribute to increased productivity. In this manner it may facilitate a paradigm shift with regard to the way CA technology is being promoted. It appears that there is an urgent need

to move away from ‘one-size-fits-all’ or “single bullet” approach used while promoting CA as optimal techniques because corresponding benefits tend to be site-specific and often vary depending on farmer’s need (Tittonell *et. al*, 2012). Thus there is need for alternative approaches towards CA via promoting increased flexibility as suggested by Andersson and D’Souza, (2013). The focus thus may need to be redirected at trying to integrate some CA concepts into existing farmers’ common practice instead of being rigid in enforcing principles (Tittonell *et. al*, 2012).

Soil covering with crop residue seems to be an important feature in CA which can be more readily harnessed and integrated into conventional ploughing system by smallholder farmers in Zimbabwe. This experiment showed that combining mulching with standard tillage practice appears to conserve water and to enable more efficient utilisation of water through intercropping system. Increasing the flexibility of promoted CA-inspired approach, including use of mulched-based conventional tillage may facilitate more effective adaptation of water and soil-conserving production techniques. Use of this intermediate intervention may serve as a transition towards more drastic, demanding and risky types of CA techniques that tend to require more time, skills and/or inputs to provide tangible benefits to smallholder farmer. In this manner we provide a ‘win-win’ situation because both water and soil resources are being conserved and used more efficiently while farmers also directly benefit in terms of income and/or human nutrition via cultivation of complementary crops. Further efforts in this regard, may be redirected towards improving the availability of plant residue (mulching material).

Emphasis on the need for reduced tillage system as part of the CA package, potentially conflicts with the role of conventional tillage system in ensuring an optimal seedbed for crop establishment as well as providing effective weed control (Kent *et. al*, 2001). And according to findings by Miriti *et al* (2012), both processes control and govern initial crop establishment, growth and final yield. Recruiting of labour to do hand weeding is a challenge in smallholder farming system in Zimbabwe due to declining participation of youth as most of them are migrating to urban areas in search of better life (personal experience during the study). Use of herbicides to address this challenge also comes with major challenges due to the lack of knowledge on their use and poor access to such capital-intensive inputs, lack of supply networks and technical support.

5. Conclusion

We wanted to find out how different tillage systems when combined with mulching affect maize-cowpea cropping systems in terms of crop yield and WUE. This study indicated that there was a positive interaction among tillage, mulching and cropping system with regard to improving crop productivity and WUE in which we hypothesized that conventional tillage system (a common farmer practice in Zimbabwe) when combined with mulching conserves soil moisture more effectively compared to corresponding reduced tillage system thereby supporting intercropping of maize and cowpea as a more efficient and productive cropping system compared to mono cropping of either of these two crops. The findings of this study were in agreement to what we had hypothesized.

Soil water was more conserved under mulched-conventional tillage compared to the corresponding reduced tillage system and this resulted in improved crop productivities (biomass, grain and income) and efficiencies with regard to water and land usage in maize-cowpea intercropping system compared to mono cropping of the two crops. Furthermore this combination even improved the soil in terms of the SOM. Crop yields under reduced tillage system were depressed by weeds (in Ushe for instance) and it is evident that the reduced tillage system component can be a challenge to the adoption of CA in smallholder farming system where labour to do hand weeding can be a serious constraint.

Although CA may not be the panacea to the improvement of crop productivity as it is presented by NGOs; it still may provide inspiration on how to look and employ alternative techniques that can be more readily integrated in existing production practices. So despite the challenges regarding its adoption, CA needs to be valued as providing inspiration for spin-off “best-fit” technologies which was part of the research scope of the current study. Promoting CA as a technology which is universally applicable on the basis of being rigid and implementing it based on almost religious and rigorous set of principles may not be the best approach to address small-holders needs in Africa. Sharp contrasts, controversies and disputes have risen due to inflexibility or unbending approach on the CA principles by promoters. Therefore, a more effective approach is to disengage the principles and try to find and fit those components that most closely match what farmers are already doing. This removes the complexity of trying to promote a rather comprehensive, complex and knowledge-intensive farming technology while expecting an immediate response from farmers.

Favourable seasonal rainfall distribution during the study period did not present the typical characteristic of the rain-fed semi-arid farming system and could have greatly influenced the outcome of this study. Thus despite these promising initial findings in an effort to improve crop productivity, long-term trials under different rainfall regimes, ecological and social settings are required to substantiate them.

References

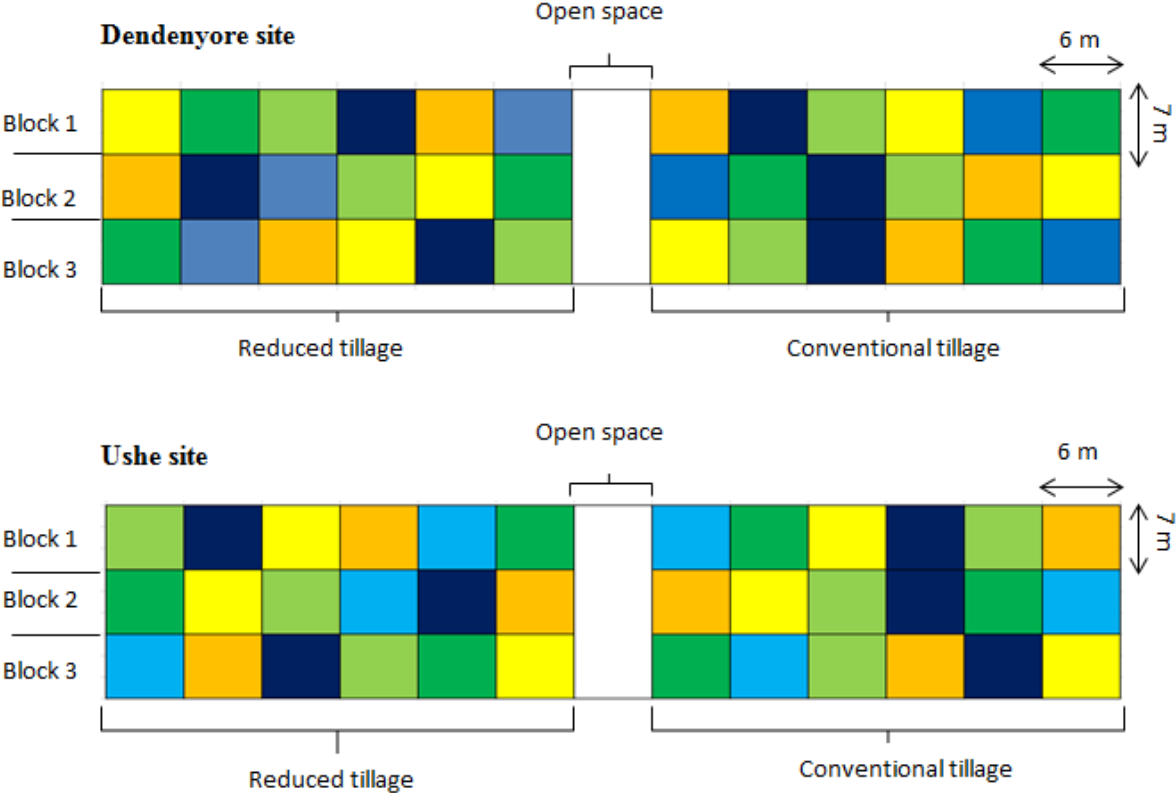
- Anderson, J.M and Ingram, J.S.I., 1993. Tropical soil biology and fertility. A handbook of methods. Second Edition. C.A.B. International Wallingford, UK, 221p.
- Anderson, T.H., Domsch, K., 1989. Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil biol. biochem.* 21, 471–479.
- Andersson, J.A., D'Souza, S., 2013. From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agric. Ecosyst. Environ.*
- Baldy, C and Stigter, C. J, (1997). Agro-meteorology of Multiple Cropping in Warm Climates. INRA, Paris.
- Brady, N.C. and Weil, R.R. (1999). The Nature and Properties of Soils, (12th edn.), Prentice Hall, Inc, New Jersey. USA. 73 – 81.
- Dixit, P. N., Cooper, P. J. M., Dimes, J., & Rao, K. P., 2011. Adding Value to Field-Based Agronomic Research through Climate Risk Assessment: a Case Study of Maize Production in Kitale, Kenya. *Experimental Agriculture*, 47(02), 317–338.
- Erenstein, O. (2002). Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. *Soil and Tillage Research*, 67(2), 115–133.
- Erenstein, O. (2003). Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture, Ecosystems & Environment*, 100(1), 17–37.
- Francis CA and Adipala E (1994) Tropical intercropping systems: What is their future? *Afr. Crop Sci. J.* 2 131-133.
- Fukai, S., & Trenbath, B. R. (1993). Processes determining intercrop productivity and yields of component crops. *Field Crops Research*, 34(3-4), 247–271.
- Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, 114(1), 23–34.
- Hatfield, J.L; Sauer, T.J.; Prueger, J.H.; 2001. Managing soils to achieve greater water use efficiency: A review. *Agron. J.*; 93, 271-280.
- Hulugalle, N.R. and Ezumah, H.C., 1991. Effects of cassava-based cropping systems on physio-chemical properties of soil and earthworm casts in a tropical Alfisol. *Agric. Ecosyst. Environ.*, 35: 55-63.
- Kassam, A., Friedrich, T., Shaxson, F. and Pretty, J. 2009. The spread of Conservation Agriculture: justification, sustainability and adoption. *J. Agr. Sustain.* 7, 292-320.
- Kent, R., Johnson, D.E. and Becker, M. 2001. The influences of cropping system on weed communities of rice in Cote d'Ivoire, West Africa. *Agr. Ecosyst. Environ.* 87, 299-307.
- Liebman. M and Dyck. E, 1993. Crop Rotation and Intercropping Strategies for Weed Management. *Ecological Applications*, Vol. 3, No. 1. (Feb., 1993), pp. 92-122.
- Miriti, J. M., Kironchi, G., Esilaba, a. O., Heng, L. K., Gachene, C. K. K., & Mwangi, D. M. (2012). Yield and water use efficiencies of maize and cowpea as affected by tillage and cropping systems in semi-arid Eastern Kenya. *Agricultural Water Management*, 115, 148–155.

- Mokhtarpour, H., Teh, C. B. S., Saleh, G., Selamat, A. B., Asadi, M. E., & Kamkar, B. (2010). Non-destructive estimation of maize leaf area, fresh weight, and dry weight using leaf length and leaf width, *5*(1), 19–26.
- Morris, R.A., Garrity, D.P., 1993. Resource capture and utilization in intercropping: water. *Field Crops Research* 34, 303–317.
- Mukhala, E., 1998. Radiation and water utilization efficiency by monoculture and intercrop to suit small scale irrigation farming. Ph.D. thesis, Department of Agrometeorology, University of Orange Free State, p. 240.
- Mupangwa, W., Twomlow, S., & Walker, S. (2012). Reduced tillage, mulching and rotational effects on maize (*Zea mays* L.), cowpea (*Vigna unguiculata* (Walp) L.) and sorghum (*Sorghum bicolor* L. (Moench)) yields under semi-arid conditions. *Field Crops Research*, 132, 139–148.
- Nezomba, H, Tauro, T.P, Mtambanengwe, F and Mapfumo, P, 2008. Nitrogen fixation and biomass productivity of indigenous legumes for fertility restoration of abandoned soils in smallholder farming systems. *Southern Africa Journal Plant Soil* 2008, 25(3) 161
- Ogindo, H. O., & Walker, S. (2005). Comparison of measured changes in seasonal soil water content by rain-fed maize-bean intercrop and component cropping systems in a semi-arid region of southern Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, 30(11-16), 799–808.
- Rasmussen, K.J. (1999). Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review, *Soil & Tillage Research*, 53 (1): 3–14.
- Saroa, G.S., Lal, R., 2003. Soil restorative effects of mulching on aggregation and carbon sequestration in a Miamian soil in Central Ohio. *Land Degrad. Dev.* 14, 481–493.
- Sidibé, A., 2005. Farm-level adoption of soil and water conservation techniques in northern Burkina Faso. *Agric. Water Manage.* 71, 211–224.
- SIWI, 2001. Water harvesting for upgrading of rainfed agriculture. Problem analysis and research needs. SIWI Report 11. Stockholm International Water Institute (SIWI), Stockholm, p. 97.
- Snapp, S.S., Mafongoya, P.L. and Waddington S., 1998. Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. *Agric, Ecos. and Env.* 71 (1998) 185-200.
- St. Clair. S.B and Lynch. J. P, 2010. The opening of Pandora's Box: climate change impacts on soil fertility and crop nutrition in developing countries. *Plant Soil* (2010) 335:101–115.
- Subbian. P, Lal R. and Subramanian K. S., 2000. Cropping Systems Effects on Soil Quality in Semi-Arid Tropics. *Journal of Sustainable Agriculture*, Vol. 16(3) 2000
- Tebrugge, F., Daring, R.A., 1999. Reducing tillage intensity - a review of results from a long-term study in Germany. *Soil Till. Res.* 53, 15–28.
- Thierfelder, C. and Wall, P.C., 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. *Soil Till. Res.* 105, 217-227
- Thompson PJ, Jansen IJ, Hooks CL (1987) Density as parameters for predicting root system performance in mine soils. *Soil Sci Soc Am J* 51:1288–1293
- Tittonell, P., Scopel, E., Andrieu, N., Posthumus, H., Mapfumo, P., Corbeels, M., Mkomwa, S. (2012). Agroecology-based aggradation-conservation agriculture (ABACO): Targeting innovations to combat soil degradation and food insecurity in semi-arid Africa. *Field Crops Research*, 132, 168–174

- Unger, P.W., Stewart, B.A., Parr, J.F., Singh, R.P., 1991. Crop management and tillage methods for conserving soil and water in semiarid regions. *Soil Till. Res.* 20, 219-240.
- Vandermeer. J, 1989. *The Ecology of Intercropping*. Cambridge University Press, New York.
- Walker, S., Ogindo, H.O., 2003. The water budget of rain-fed maize and bean intercrop. *Physics and Chemistry of the Earth* 28, 919–926.
- Wang. E., Cresswell. H., Xu. J., Jiang. Q., 2009. Capacity of soils to buffer impact of climate variability and value of seasonal forecasts. *Agric. Forest Meteorology*. 149. 38-50
- Willey, R.W., 1979. Intercropping -its importance and research needs Part 1. Competition and yield advantages. *Field Crop Abstr.* 32: 1-10.
- Willey, R.W., 1985. Evaluation and presentation of intercropping advantages. *Experiment Agriculture* 21, 119-133.
- World Reference Base (WRB) for Soils, 1998. FAO/ISRIC/ISSS. World Soil Resources Report No. 84. Food and Agriculture Organization. Rome.

Appendix 1

Field layout at study sites



Key:

- Cowpea bare
- Intercrop mulched
- Intercrop bare
- Maize mulched
- Cowpea mulched
- Maize bare