ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

Exploiting Cropping Management to Improve Agricultural Water Use Efficiency in the Drylands of Eastern Uganda

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Received: September 18, 2014 Accepted: March 7, 2015 Online Published: April 3, 2015

doi:10.5539/sar.v4n2p57 URL: http://dx.doi.org/10.5539/sar.v4n2p57

Abstract

A remarkable challenge lies in maximizing agricultural water productivity, particularly in the drought prone regions of sub Saharan Africa. It is hypothesized that water use efficiency (WUE) can be increased by selection of appropriate cropping management systems. This study seeks to establish the effects of cropping management on water use efficiency in cassava-sorghum cropping systems in the drylands of eastern Uganda. A randomised complete block design (RCBD) consisting of six treatments: sole cassava, sole sorghum, sole cowpea, cassava + sorghum, cassava + cowpea, and sorghum + cowpea, replicated three times were used. Two tillage practices; mouldboard ploughing (Mb) and, ripping (Rp) were used to assess the effect of tillage. WUE (kg ha^{-1} mm^{-1}) was calculated as a ratio of yield (kg ha^{-1}) to evapotranspiration (ET) (mm). ET was estimated using the soil water balance. WUE varied significantly (α= 0.05) between cropping systems with the highest observed in cassava (34.38 kg ha^{-1} mm^{-1}) while the lowest was 3.76 kg ha^{-1} mm^{-1} for sorghum. WUE did not differ appreciably in both Mb and Rp tillage practices. Farmers growing sole cassava could use either of the tillage practices. The best yield was recorded in cassava + cowpea cropping system under Mb ploughing and sole sorghum under Rp gave the poorest combined yield (1,676 kg ha^{-1}).

Keywords: evapotranspiration, soil moisture storage, tillage, water use efficiency

1. Introduction

Agricultural water productivity is associated with the failure to meet the Millennium Development Goals (MDGs), especially where rainfall is limited and most times with erratic distribution in sub-Saharan Africa. Farmers have been exposed to water management strategies albeit in isolation at plant, plot, and farm level (Cooper et al., 2008), but have not measured up to the challenge. Now, there is a paradigm shift among nations and international institutions towards integrated water resource management (IWRM) (Tollan, 2002; Schulze, 2004), where policy-makers are now focusing on demand management, carrying capacity of the natural environment (Snellen & Schrevel, 2004), while linking water resources directly to development initiatives (UN-HABITAT, 2003). Among the biophysical measures driving this paradigm shift is the campaign to: 1) increase water use efficiency and land productivity, 2) continue efforts to explore ways to ‘‘*grow more food with fewer drops*’’ under sustainable conditions through research and development, capacity building and spread of technology (ICID, 2005).

A major challenge in the drought-prone regions of sub Saharan Africa is to balance the factors controlling crop water use and soil moisture availability (Rockström, 2003; Boko et al., 2007). Water use efficiency (WUE) is envisaged to provide a solution to this challenge by enhancing the partitioning of the available rainfall through manipulation of tillage and cropping systems. Well aware that efficiency is an input-output relationship, agricultural production undergoes several biophysical processes which most often dictate the final product (Hsiao et al., 2007) therefore, ability to relate an appropriate biophysical process to the harvestable crop product is a must in improving agricultural water use efficiency. Further still, the socioeconomic implications of delivering, using, managing, or buying water have exacerbated the impacts of supplying water for agricultural production, making farmers in the drylands more vulnerable.

Suggestions to improve and sustain food production in the drylands can be through choice of practices and cropping systems that demand less nutrients, labour, and capital for the production process (Andales et al., 2006) but also use water more efficiently. Reviews of WUE methods reported by Nielsen et al. (2005) show that use of crop residues on the soil surface increased WUE of corn and sunflower by 28 and 17% respectively due to change from conventional tillage to no-till in Kansas, USA while, WUE of winter wheat at Akron, Colombia increased from 6.9 to 7.5 and to 8.4 kg ha^{-1} mm^{-1} in a wheat-fallow-conventional till, wheat-fallow no-till, and wheat-corn-fallow no-till respectively. On the contrary, crop residues have several competing users in eastern Uganda like: dry season feed for livestock, thatching material for houses and, are easily damaged by termites, therefore use of crop residues for soil surface cover may not be feasible.

Soil moisture fluxes, a function of precipitation, runoff, infiltration, and evapotranspiration, determine crop water use (Allen et al., 1998; Angus & Herwaarden, 2001; Nielsen et al., 2005) however, water use can be regulated through choice of seedbed management practices that make soil moisture more available for uptake by crops. It is also true that water use is dependent on the inherent physiology and growth habit of the plant vis-à-vis the environmental stresses (Nielson et al., 2005; Makoi & Ndakidemi, 2010), notwithstanding the fact that, the prevailing microclimate can be engineered through choice of crops and cropping systems. Indeed, the process worthy exploiting in this soil-plant-atmosphere relationship is how rainwater is partitioned into water used by the crop and/or stored within the root zone (“green” water) under the different tillage and cropping management practices. In this case, WUE would refer to a ratio of crop yield to water used (yield/evapotranspiration) yet crop water use is subject to how farmers manage the crop in question.

In the drylands of eastern Uganda cassava (*Manihot esculanta*), sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*) are dominant staple crops in most smallholder households. These crops are cultivated as pure stands in a crop rotation plan or by intercropping (Adipala et al., 1997; Ainembabazi et al., 2005; Otim-Nape et al., 2005; Whyte & Kyadondo, 2006). The common practice is to till the soil using animal power (Tenywa et al., 1999), usually up to a plough depth of 20 cm therefore moisture storage and consequently root penetration is limited to this volume. For purposes of this study, crop combinations and field management strategies used in growing these crops defines the cassava-sorghum based cropping system. Additionally, rainfall in this area was estimated to be partitioned thus: 93.2% ET, 3.8% runoff (Wasige et al., 2004), however, ET of up to 200% was recorded in a sorghum field indicating a severe negative water balance (Kizito, 2004). Therefore, the possibility of translating this magnitude of ET (93 to 200% of rainfall received) into yields is great, especially when the proportion of evaporation to ET is reduced and a steady water supply to the crop is ensured through improved soil moisture storage.

Crop and seedbed manipulations that positively impact on the soil water balance were suggested (Benli et al., 2006; Lipiec et al., 2006; Turner, 2004) and have been popularized as ‘conservation agriculture’ (FAO, 2007, Verhulst, et al., 2010).Conservation practices are based on promotion of biophysical processes above and below the ground. These soil and crop manipulations could target reducing evaporative losses from plant and soil surfaces while, increasing storage in the root zone and transpiration (Gicheru et al., 2004; D’Haene et al., 2008), with the resultant quantity being improved WUE. Agronomists have defined water use efficiency as a ratio of harvestable yield to water consumed by the crop (Turner, 2004; Passioura, 2006; Rijsbern & Manning, 2006; Bouman, 2007; Hsiao et al., 2007) in a simplified expression;

$$WUE(\text{kg ha}^{-1}\text{mm}^{-1}) = {}^{\text{Crop yield (kg ha}^{-1})}\!\Big/_{\text{Water supply (mm)}} \quad (1)$$

In this study WUE is defined as the ratio of harvestable (marketable) crop yield to evapotranspiration (water used by the crop) on the understanding that, the maximum rate of evapotranspiration, usually a function of available water in the soil, determines water uptake by a crop (Abbate et al., 2004; Ritzema, 2006; Bodner et al., 2007) and consequently the total yield. Water supply and water used by the crop are related and can be derived from the water balance components. Since it was not possible to precisely account for the loss of productive water through evaporation, the collective term of evapotranspiration was adopted to refer to water used by the crop.

Taking advantage of the knowledge on water balance parameters, seedbed management practices and manipulation of cassava, sorghum, cowpea cropping cycles to manage water resources in rainfed agricultural ecosystems is still a challenge. This study therefore, aimed at establishing the effect of tillage and cropping systems on water use efficiency in cassava-sorghum cropping systems in the drylands of eastern Uganda.

2. Materials and Methods

2.1 Study Site Description

The study was located in eastern Uganda (34º 0' E and 1º 40' N) in the Usuk sandy farm-grasslands agro-ecological zone (Wortman & Eledu, 1999) found in the greater Teso farming system. The Teso farming system lies at approximately 1036 and 1127 m above sea level and is predominantly an agro-pastoral system (Parsons, 1960). The area covers the administrative districts of Amuria, Katakwi, Kumi, and Soroti in eastern Uganda (Appendix 1).

2.1.1 Climate

The area experiences bimodal rainfall where the long rain season is usually from mid-March to June and the short rain season is from August to November. There is a short dry spell between the two rain seasons i.e. mid-June to mid-July, however areas bordering northeast experience earlier dry seasons. The seasonal mean precipitation ranges between 650 and 900 mm, but up to 25-30% of the precipitation is received outside the annual growing period (Kayizzi et al., 2007).

The mean annual maxima and minima temperature is 31.3 ºC with an annual mean of 24 ºC. Extreme temperatures of approximately 35^{0}C are common in the month of February. Potential ET is higher than precipitation for most part of the year (Table 1). Relative humidity ranges from 66% to 83% at 0900hours East African time and 35% to 57% at 1500hours, thereby reducing chances of rainfall. This condition is expected to support crop growth but the seasonal growing period is reduced to 72-120 days (Komutunga & Musiitwa, 2001).

Table 1. Long-term mean monthly rainfall, evapotranspiration and temperature for Soroti, eastern Uganda

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Rainfall (mm)	20.1	47	72.9	182.9	192	125	125	184.9	142	116.1	72.5	38
ET (mm)	121.7	118.9	129	106.7	90.2	90.8	86.2	92.7	92.7	106	108.2	111
Temp (ºC)	25.5	25.9	25.9	24.4	23.5	23.1	22.5	22.6	23.3	24.1	24.5	24

Source: Major land resources areas of Uganda, Yost and Eswaran, (1990) p. 96.

2.1.2 Soils

The soils of the Teso region originate from rocks of the precambrian age basement complex comprising mainly granites, mignalites, gneiss, schists and quartzites. These rocks give rise to four major soil series Serere and Amuria catenas, Metu complex and Usuk series that are mainly of the ferralitic type (sandy sediments and sandy loams). The dominant soil type in the area is *Petroferric Haplustox*. Sandy soils stand out in the area (Ssali, 2000) are well drained, friable and characterized by low water holding capacity and low organic matter levels which intensify the water deficit challenge. The soil physical and chemical properties at the experimental site are described in Table 2 below.

2.1.3 Land Use and Livelihood Strategies

Land use and livelihoods are inextricably linked (ecologically, economically, socially, and politically) that any change in former dramatically impacts on the latter. The eastern Uganda population is predominantly agro-pastoral basically producing at subsistence level (Whyte & Kyaddondo, 2006). Now, most households in the Teso region derive their livelihood on increasingly small land holdings ranging between 0.5 to 4 ha (national average = 0.4 to 3ha) per household (Okwi et al., 2006), hence forcing intensive production systems and/or seeking non-farm income in order to ensure food self sufficiency. Crop production is reported to be declining (NARO, 2002), despite the use of nutrient inputs and pest management strategies (Kayizzi et al., 2007), a limitation thought to arise from water stress conditions. Cassava is a key root crop (NARO, 2002) serves both as a major source of calorie intake and a ‘new’ cash crop to over 60% of the households in eastern Uganda (Otim-Nape et al., 2005) while, sorghum is ranked 2nd most important cereal in eastern Uganda. These major crops are grown in root crop/cereal/legume mixtures (Otim-Nape & Zziwa, 1990) like, the sorghum-cowpea intercrop (Adipala et al., 1997) or crop rotations beginning with cassava (Otim-Nape et al., 2005)mainly for pest management, soil fertility improvement and income aspects yet, these crop mixtures have a potential to exploit in integrated water resource management practices. Therefore, conditioning the already known crop, tillage and crop management practice to improve water use efficiency is thought to be a major contribution to land use and livelihood security in the cassava-sorghum based cropping systems in eastern Uganda.

Table 2. Soil Physical and chemical characteristics at the study site

	Profile depth	
	0-10 cm	*20-40 cm*
Clay (%)	4	4
Silt (%)	6	28
Sand (%)	90	68
OM (%)	2.72	1.01
Textural class (FAO)	Sandy	Clay loam
Bulk density (g cm^{-3})	1.63	1.54
K_{sat} (cm hr^{-1})	5.8	7.6
pH (H_2O)	5.9	5.2
CEC (me/100 g)	9.2	10.2
N (%)	0.12	0.1
P (me/100 g)	2.15	1.25
K (me/100 g)	0.2	0.21
Na (me/100 g)	0.05	0.09
Ca (me/100 g)	6.21	4.01
Mg (me/100 g)	2.11	1.21

2.2 Experiment Design

The study was set in a randomised complete block design (RCBD). The treatments consisted of six cropping systems, i.e. i) sole cassava, ii) sole sorghum, iii) sole cowpea, iv) cassava + sorghum, v) cassava + cowpea, vi) sorghum + cowpea and replicated three times. Two tillage (seed bed management) practices, i.e. mouldboard ploughing and ripping using ox-drawn equipment were practiced. Each experimental unit was 10 × 7 m separated by a 1m gap. Replicates were located on a similar slope profile along a defined transect in order to minimise variations due to lateral soil moisture flux and soil fertility gradient. The experiments were conducted in three growing seasons. Cassava was planted in the first rains of 2010 (late March), using a 20 ± 5 cm cutting with a spacing of 1 m × 1 m, giving a total plant population of 10,000 plants ha $^{-1}$. Harvesting was done in April 2011. Unlike the cassava crop, sorghum and cowpea were planted three times i.e. late march 2010, August 2010 and April 2011.

2.3 Determination of Evapotranspiration

The soil water balance was used to derive ET (Abbate et al., 2004; Benli et al., 2006; Bodner et al., 2007). When micro-meteorological data was not available to run the original Penman–Monteith water balance model (Van Vosselen et al., 2005), some parameters representing the classical law of mass conservation were used. Precipitation (P) was the only source of moisture into the soil system because there was no irrigation (I = 0) and there was no groundwater within reach of the root zone (CP = 0). Subsurface flow into (SF_i) and out (SF_o) of the soil was negligible due to the small slope gradient (< 3%) and the surface conditions could not allow runoff to take place (RO = 0). Therefore the soil water balance equation is re-arranged to give the expression;

$$P = ET + DP + \Delta S \tag{2}$$

where; *ET* is evapotranspiration,

DP is loss to the soil layers below the root zone, and

ΔS is the amount stored in the soil at a given period.

The basic soil-plant-atmosphere relationship being explained here is the balance between rainfall received (*P*), water retained in the root zone (ΔS), water percolating beyond the root zone (*DP*) and, water used by the crop (*ET*). We notice here that two basic parameters; *P* and ΔS are measured and *DP* is estimated. But in principle, *DP* only occurs when the upper horizons are saturated and can be estimated based on Darcy's law (Ritzema, 2006) using the equation;

$$DP = -k\frac{\partial H}{\partial Z} \tag{3}$$

where; k is hydraulic conductivity (mm day^{-1})

$\frac{\partial H}{\partial Z}$ is the hydraulic gradient

However literature indicates that in dryland agricultural ecosystems, where the slope gradient is almost flat deep drainage is negligible. In particular, a water balance model for this catchment indicated that only 8.3% of the rainfall received was stored (Wasige et al., 2004), hence a minimal volume is expected to go to deep percolation. Therefore, to estimate *ET* throughout the life cycle of a crop, we need to determine soil moisture content at planting time and at crop maturity. Angus and van Herwaarden (2001) used the expression;

$$ET = P + \Delta S \tag{4}$$

where, ΔS represents soil water content at sowing time minus soil water content at maturity.

2.4 Crop Yield Determination

2.4.1 Cassava

The main yield components used was fresh and dry storage root weight (Ntawuruhunga et al., 2001). Measurements were done on five plants from each plot randomly chosen during harvest of cassava in the different treatments. Total fresh weight was taken after uprooting the plant and weighed in the field using a commercial weighing scale (25 kg ±10 g), and then marketable storage roots were removed and weighed separately. For the measurements done in the laboratory, one storage root was randomly taken from each of the five plants selected in each plot. This was used to obtain the average diameter, length and fresh weight of the storage root. The storage root was prepared for drying by manually removing the peel (corky periderm and cortex) using a kitchen knife, then the starchy flesh was sliced to thin chips to ease sun drying. In order to ensure uniform level of drying, the materials were placed in an oven at 60 ^{o}C for 24 hours before taking the dry weight measurements. The dry weight of the storage roots was taken using a precision laboratory scale (1000 g ± 0.001 g) and the values used to derive the yield per hectare.

2.4.2 Cowpea

The yield parameters taken for cowpea include; number of pods per plant, number of seeds per pod, weight per hectare. A one square meter area was randomly chosen in each plot then the number of plants counted and the average number of pods per plant determined. Mature pods were harvested, air dried and hand threshed. Grain weight was taken after all seeds were oven dried at 60 ^{o}C for 24 hours.

2.4.3 Sorghum

The sorghum variety grown has one head (panicle) per plant. Ten plants were randomly selected from the mid rows per plot from which panicles were cut using a hand knife. Heads from each plot were sun dried, then threshed by abrasion using light pressure from a piece of wood. Traditionally, in eastern Uganda sorghum and millet are threshed by beating harvested heads with a dry smooth piece of wood after sun drying.

2.5 Determination of Water Use Efficiency

The yield obtained is dependent on the water used (evapotranspiration) throughout the growing period, which defines WUE. Therefore after substituting water supply with *ET* in Equation 1, we obtain a working expression following similar arguments by Moitra et al. (1996), Xu and Hsiao, (2004), and Payero et al. (2008).

$$WUE(\text{kg ha}^{-1}\text{mm}^{-1}) = \text{Crop yield (kg ha}^{-1}\text{)} / \text{ET (mm)} \tag{5}$$

2.6 Statistical Data Analysis

Data were analysed using GenStat software. Analysis of variance (two way ANOVA) was performed to identify differences between treatments and means separated using LSD at α=0.05. However, the cowpea and sorghum crop was grown for three seasons hence, a variation due to season introduced. The first two seasons had three replicates and the third season was replicated four times, so the ANOVA for unbalanced designs was adopted where season and replication were blocked as nuisance factors. However, some further analysis would require introduction of season as a factor.

3. Results and Discussion

3.1 Effect of Cropping Management Practice on Evapotranspiration

Evapotranspiration (*ET*) was calculated following the water balance model. Since, precipitation (P) cannot vary in all treatments, and the change in soil moisture content (ΔSM) was known then, ET as a sum of P and ΔSM, was dependent on soil moisture storage, represented by the soil water content at sowing time minus soil water content at maturity and the ability of the crop to extract moisture from the soil.

ET varied significantly between cropping systems (F pr = <0.001) but, did not show any difference with respect to tillage practice (F pr = 0.105) at 95% confidence level. On the contrary, the interaction between tillage practices and cropping systems presented significant differences (F pr = <0.001). The sole cassava (526.5 mm) and cassava + cowpea (524.0 mm) cropping pattern recorded higher ET under Rp than Mb while, the sorghum + cowpea intercrop performed slightly better in Mb (526.5 mm) than Rp (519.3 mm) ploughed plots. The ET for sole cowpea cropping system was similar and highest in both tillage practices (Figure 1).The rainfall data used here were average records of two non-recording rain gauges, one located adjacent to the experiment site and the other at the Soroti Flying School Meteorological Department located about 3 km from the experimental site. The amount of rainfall received during the growing seasons was 728.4, 350.0 and 477.0 mm for season I (March – July 2010), season II (August – November 2010) and season III (April – July 2011) respectively. The ΔSM was derived from soil moisture content observations made through the growing period at two soil profile depths (0-10 and 20-40 cm).

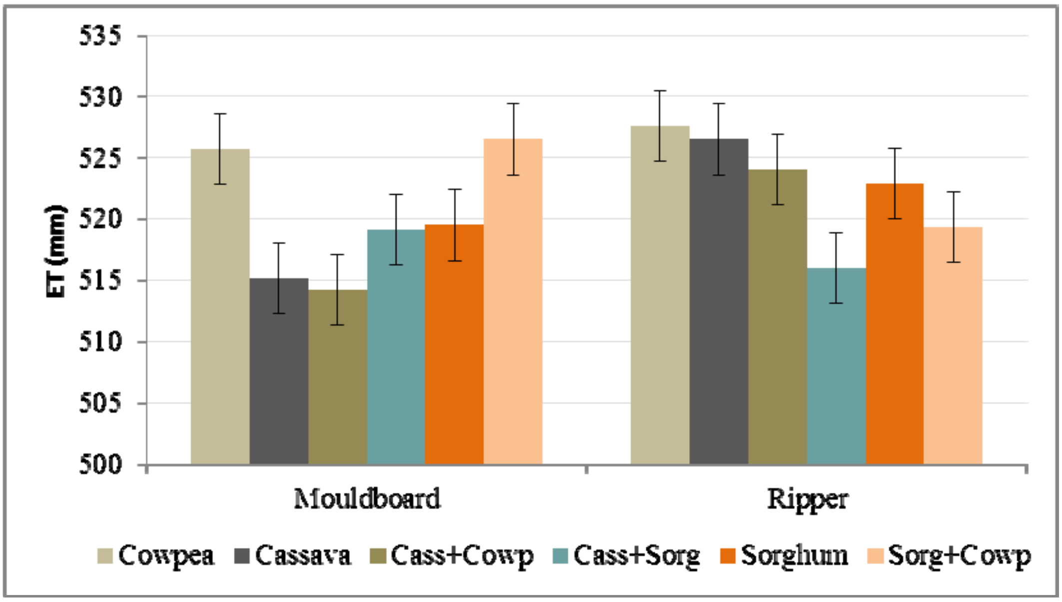

Figure 1. Effect of cropping management on evapotranspiration in the cassava-sorghum cropping system

There was a significant difference in ΔSM between, cropping systems, tillage x cropping system interaction, seasons (F pr = < 0.001) and tillage practice (F pr = 0.044) at 95% confidence level.

When effect of seasons was removed and each season analysed independently, it was observed that tillage practice in season I (F pr = 0.065), tillage practice x cropping system interaction in season II (F pr = 0.165) were not significantly different at 95% confidence level. In season III all treatments were significant (F pr = <0.001).Therefore for the calculation of the water balance, the accumulated means for the three seasons were used.

There was more water extracted from the soil system during the growing period as indicated by the negative sign on the values where cassava was grown as a sole crop or as an intercrop (Table 3).

Table 3. Effect of cropping management on soil moisture storage

Tillage Practice	*Cropping system*	*ΔSM(mm)*
Mouldboard	Sole Cassava	-4.215*d*
	Sole Cowpea	1.031*ba*
	Sole Sorghum	-2.054*c*
	Cassava + Cowpea	-4.736*d*
	Cassava + Sorghum	-2.275*c*
	Sorghum + Cowpea	1.410*b*
Ripper	Sole Cassava	1.441*b*
	Sole Cowpea	1.962*bc*
	Sole Sorghum	-0.390*a*
	Cassava + Cowpea	0.175*a*
	Cassava + Sorghum	-3.832*d*
	Sorghum + Cowpea	-2.154*c*

Note: *Different letters against the values indicate significant differences at α = 0.05.*

The high negative values exhibited by sole cassava, cassava + cowpea, cassava + sorghum, and sole sorghum cropping systems under mouldboard ploughing compared to the positive and relatively low values under ripper ploughing show that the crops under ripping are less likely to show signs of water stress during the growing period. It was noted that the ripper ploughing practice could hold more water in the 20-40 cm horizon which could then be made available to deep rooted crops like cassava and cowpea.

3.2 Effect of Cropping Management on Yield of Cassava, Cowpea, and Sorghum

The cassava crop was grown between March 2010 and April 2011 (one season) while, the cowpea and sorghum crop was grown for three seasons (March – July 2010; August – November 2010; April – July 2011). Generally, the yield of cassava cowpea, and sorghum varied between the two tillage practices and the cropping systems (Table 4). On introduction of the effect of seasons only intercrops involving sorghum varied significantly (F pr = 0.001) at 95% confidence level.

Much as the marketable yield of cassava can be both in terms of fresh weight and dry weight, for this study dry weight was used in order to harmonise the crop yield records for all crops. The yield of cassava differed significantly between cropping systems but was similar as a sole crop under mouldboard and ripper ploughing practices. The cassava + cowpea intercrop in the mouldboard ploughed plot recorded the highest cassava yield (20,023 kg ha^{-1}) compared to other treatments.

Cowpea yield was significantly different in both tillage (F pr = 0.013) and cropping systems (F pr = <0.001) but, the interaction between tillage and cropping systems were non-significant (F pr = 0.102). Additionally, variation due to seasons was not significant (F pr 0.161) at 95% confidence level. The yield of sorghum was significantly different between tillage practices (F pr = 0.009), cropping systems (F pr = 0.004) and season (F pr = 0.001) were recorded.

The traditional practice of growing cassava as a sole crop under mouldboard ploughing gave similar yields like ploughing using a ripper. However, the high yield recorded when cassava was intercropped with cowpea (20,023 kg ha^{-1}) under mouldboard ploughing is evidence that these crops complemented each other in resource use. Agronomists and soil fertility scholars have advanced the contribution of legumes in soil fertility enhancement in mixed cropping systems however, efficient use of soil moisture provides the missing link in enhancing productivity in these cropping systems. Additionally, the cowpea yield in the cassava + cowpea intercrop was still better than in the combinations involving sorghum under both tillage practices. The observed yield here were majorly contributed by the first season crop which used most of the soil moisture before the cassava crop established.

Table 4. Effect of cropping management on yield of cassava, cowpea and sorghum

Treatments		*Yield (kg ha^{-1})*		
Tillage Practice	Cropping system	Cassava	Cowpea	Sorghum
Mouldboard	Sole Cassava	16560b		
	Sole Cowpea		8397d	
	Sole Sorghum			1179b
	Cassava + Cowpea	20023c	3570b	
	Cassava + Sorghum	11101a		1279c
	Sorghum + Cowpea		2853a	894a
Ripper	Sole Cassava	14282b		
	Sole Cowpea		5771c	
	Sole Sorghum			1679d
	Cassava + Cowpea	11962a	2320a	
	Cassava + Sorghum	11247a		1260c
	Sorghum + Cowpea		2703a	1110b

Note: *Different letters against the values in each column indicate significant differences at 95% confidence level.*

Overall, cowpea yield was higher under Mb than Rp across all three seasons (March – July 2010; August – November 2010; April – July 2011). It was observed that cowpea under Rp had a thick vegetative cover and was frequently attacked by pests. Adipala et al. (1997) reported that high humidity under the leaves of cowpea encourages pest build up, hence the cowpea yield here was compromised by pest damage. Additionally it is a traditional practice in eastern Uganda to harvest cowpea leaves for use as a vegetable and studies show that grain yield improved with a degree of defoliation (Rahman et al., 2008) but, here farmers would give priority to the mouldboard plots than the ripper plots. To this effect the highest yield (8397 kg ha^{-1}) recorded for the sole crop was under mouldboard ploughing were preferential leaf harvesting was done because the field was cleaner. Also the yield difference could be attributed to the optimum plant population (av. plant density = 12667 plants ha^{-1}) giving a relatively maximum and uniform use of soil and water available.

The yield of sorghum was highest in the sole crop under ripper ploughing (1679 kg ha^{-1}). The cassava + sorghum intercrop in both tillage practices was comparable (Table 4) while, the lowest yield was observed in the sorghum + cowpea intercrop in Mb. Cowpea has a quicker growth and establishment habit hence, could have out competed the sorghum crop for nutrients and moisture. We also noted that in the cassava + sorghum intercrop, the sorghum crop is not stressed by the cassava crop since it has a much slower rate of establishment.

3.3 Effect of Cropping Management Systems on Water Use Efficiency

Water use efficiency (WUE) varied significantly between cropping systems (F pr = < 0.001) but was similar under mouldboard (Mb) and ripper (Rp) ploughing (F pr = < 0.166) at 95% confidence level. The highest WUE was recorded in cassava at 34.38 kg ha^{-1} mm^{-1} and the lowest was in sorghum at 3.76kg ha^{-1} mm^{-1} (Figure 2). When the effect of season was considered as a main factor in the analysis, there were significant variations (F pr = <0.001) in WUE across the three seasons (Figure 3).

The variation in WUE observed between cropping systems could be attributed to soil moisture characteristics, although growth and physiological characteristics of the crop could be considered. The material that constitutes the yield could partially contribute to the difference i.e. root tuber in cassava compared to the grains in sorghum and cowpea (Steduto et al., 2007). The ability of the crop to convert assimilates to biomass is primarily determined by chemical composition of the crop and is not easily changed by environmental factors such as water supply except, where there are extreme changes in respiration due to change in thermal regimes (Hsiao et al., 2007). For instance, the cassava crop was in the field through two seasons and was able to use most of the moisture that was stored in the soil even during the dry season of the year.

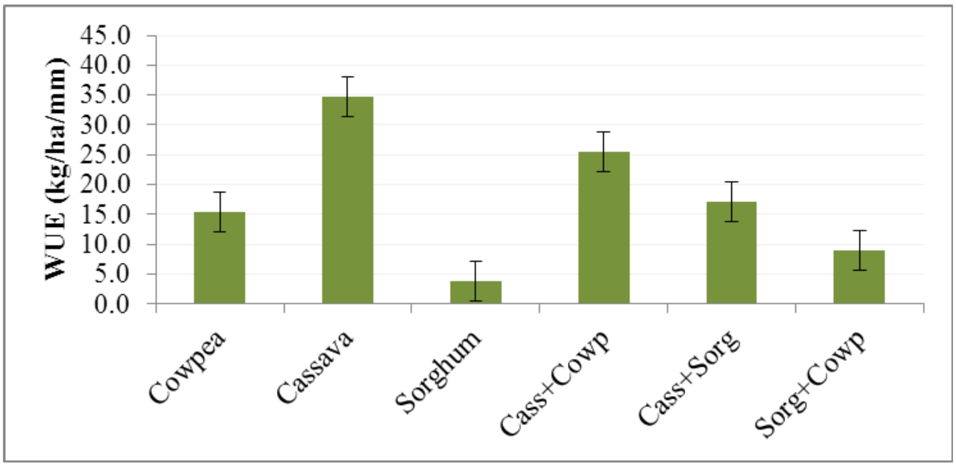

Figure 2. Behaviour of WUE (kg/ha/mm) under different cropping system in eastern Uganda

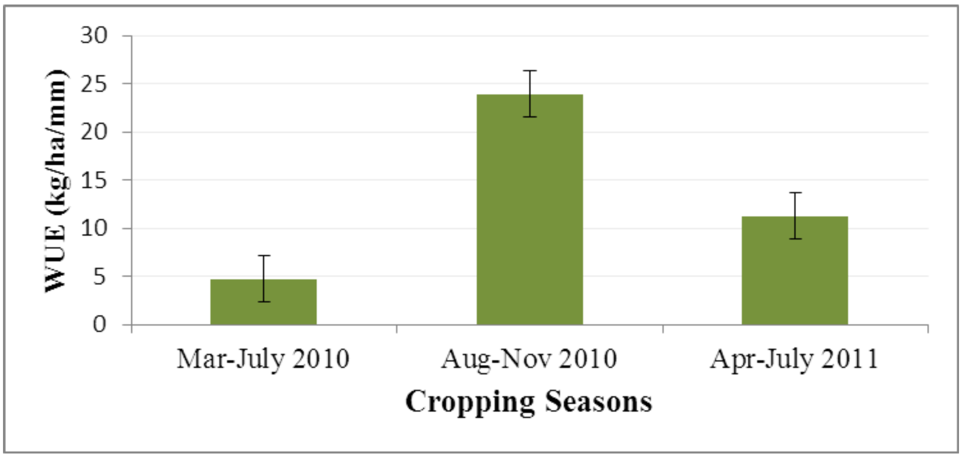

Figure 3. WUE (kg/ha/mm) across three seasons during the study period (March 2010- July 2011) in the cassava-sorghum cropping systems in eastern Uganda

There was a noticeable decrease in soil moisture storage for this cropping system as crop growth progressed. Much as ET for cassava was high the crop seems to have been able to reduce the proportion of moisture losses arising from evaporation.

Interestingly though, cassava + cowpea intercrop recorded better WUE than sorghum + cowpea. The feeding volume of the cassava and cowpea was stratified through the root zone that instead of resource competition there was a synergistic relationship. The moisture available before the cassava crop establishes was exploited by the quick growing cowpea. It was also observed that cowpea offered a surface cover of over 50% by 8 weeks after planting hence, reducing evaporation losses and encouraging transmission to the lower section of the root zone. Hsiao et al. (2007) noted that the water stored in the root zone can merge with water from the rain at the point of root zone water hence, improving efficiency of water delivery at the soil-plant- atmosphere interface. Therefore, for farmers in eastern Uganda who usually intercrop cassava with sorghum or cowpea, this study shows that cassava + cowpea maximizes the use of available water in the soil system. It was noted that, tillage using a ripper plough stored more water in the 20-40 cm rooting zone. This process can be enhanced by carefully synchronizing tillage practices with cropping systems to improve water use efficiency in the cassava-sorghum cropping system.

4. Conclusion

Evapotranspiration (ET) varied significantly between cropping patterns and the interactive effect of cropping and tillage management. Sole cassava (526.5 mm) and cassava + cowpea (524.0) cropping system recording a higher ET under ripper ploughing (Rp) than mouldboard ploughing (Mb) while, the sorghum + cowpea intercrop performed better in Mb than Rp.The change in soil moisture content was more negative in the mouldboard ploughed plots indicating that more water was extracted than in the ripped plots. The sole cassava, cassava + cowpea, cassava + sorghum, and sole sorghum cropping systems under mouldboard ploughing had a more negative change in moisture content compared to the positive and relatively low values under ripper ploughing.

There were variations in water use efficiency (WUE) due to choice of crop management, but WUE was similar in both mouldboard and ripper ploughed plots. Cassava had the best WUE (34.38 kg ha^{-1} mm^{-1}) while sorghum (3.76 kg ha^{-1} mm^{-1}) recorded the low values. However, there is need for further studies to ascertain the contribution of physiological factors on this difference. There is need to take measures to maintain soil moisture and improve water use efficiency in dryland cropping systems.

Much as there were differences in total yield between tillage practices and cropping systems, in sole cassava cropping system yield was comparable under both mouldboard and ripper ploughed plots. Cassava + cowpea intercrop under mouldboard ploughing gave the best cassava yield compared to other cropping patterns. Crop management significantly influenced the yield of cowpea across the three seasons. Overall, cowpea yield was higher under mouldboard ploughing than ripper ploughing across all three seasons and can be related to the availability of soil moisture in the 0-10cm layer early in the season for quick establishment. Sorghum responded differently to tillage practices, cropping systems and exhibited a strong variation between the three seasons.

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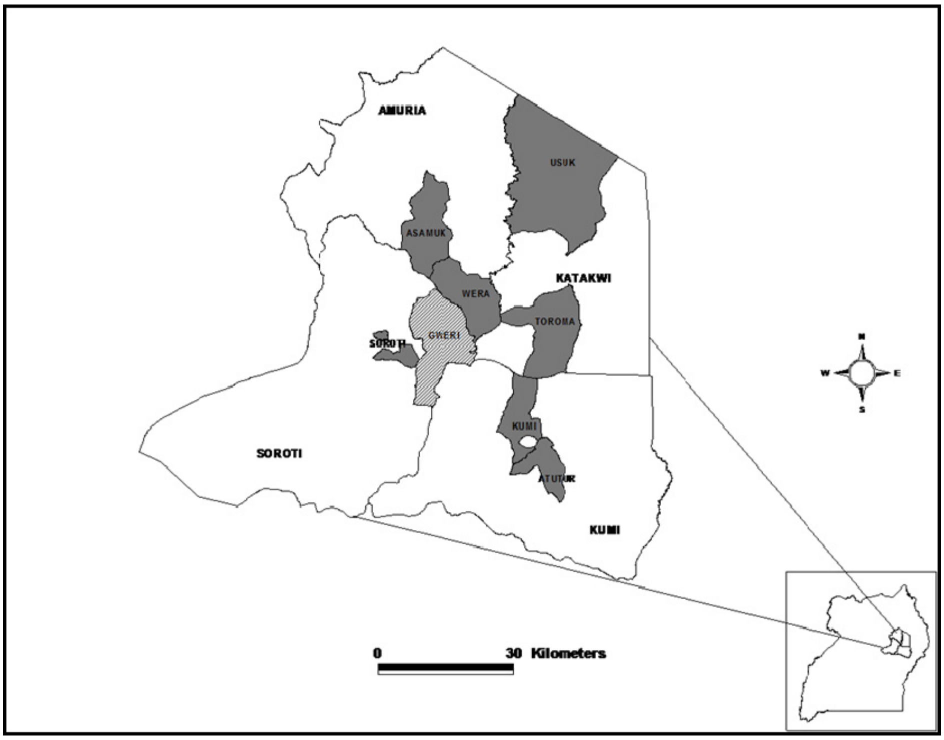
Appendix. Map of the Teso region in eastern Uganda showing the Districts of Amuria, Katakwi, Kumi and Soroti. Inset is the Map of Uganda



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