Science Arena Publications
Specialty Journal of Agricultural Sciences
ISSN: 2412-737X
Available online at www.sciarena.com
2019, Vol 5 (2): 1-14

Effects of Tillage and Crop Residues Management in Improving Water-Use Efficiency in Dryland Crops under Sandy Soils

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Abstract: *A 3-yr field experiment to evaluate effects of tillage and residue management on soil water storage (SWS), grain yield, harvest index (HI) and water use efficiency (WUE) of sorghum was done in sandy soils. Treatments were conventional (CT) and minimum (MT) tillage without residue retention and conventional and minimum tillage with residue retention. Change in SWS was negatively higher under CT and MT than in CT × RT and MT × RT, especially in the 0-10 cm soil layer. Grain yield and HI were significantly (P <0.05) lower in CT and MT than CT × RT and MT × RT. Grain yield and HI were significantly (P <0.05) positively correlated to WUE but WUE significantly (P<0.05) negatively correlated to sand (%) particle content. The SWS was lower in winter but higher in summer and was significantly correlated to soil organic carbon (SOC), sand(%), grain yield (t/ha), HI and WUE. The WUE increased from first to last cropping seasons under returned residues that promoted SOC buildup. Soil tillage decreased effects of residues on SWS, WUE, grain yield and HI. Understanding and considering the WUE in crops can be a primary condition for cropping system designs. The findings pave way for further research and allowing valorization of water in crop production.*

Keywords: Organic matter, Rainfall, Sand, Water use efficiency, Yield

INTRODUCTION

World-over, crop production is dependent on soil water availability either directly through rainfall captured in the soil or indirectly as soil water applied via irrigation (Hatfield, 2011). However, the amount and distribution of natural rainfall are negatively affecting crop productivity in many parts of the world especially in sub-Saharan Africa. The current increasing variability in both temperatures and precipitation has accelerated the problem and raises the question of how to enhance crop water use efficiency (WUE) in different cropping systems (Tadele, 2017). Again, the soils of the world continue to be degraded such that the critical properties which are linked to WUE of the cropping systems are being negatively impacted (Liu *et al*, 2015). Therefore increasing water use efficiency is critical to ensuring continuity on food, feed, fuel, and fibre production to sustain the world's ever increasing population. Optimizing factors that influence WUE will, therefore, stabilize crop productivity across a range of climates. However, the ever-increasing challenges of climate change correspond to the urgency with which we should prioritize the problem and begin to understand the implications of the interactions between soil management practices and WUE. In the wake that many farmers in the sub-Saharan Africa and the Mediterranean region that practice dryland cropping, increasing WUE is a priority. Dryland cropping refers to those rainfed agricultural areas where the average water supply to the crop limits potential yield to less than 40% of full (water-unlimited) potential (Hatfield, 2011).

Currently water availability has become a limiting factor in agriculture than in the past (Turner, 2004; Colecchia *et al*., 2015). Supplemental irrigation can benefit yields and water use efficiency in water-limited environments but the potential is decreasing, with competition for water for industrial uses (Troccoli *et al*, 2015). Thus, agriculture will become increasingly dependent on rainfall as its sole source of water, and maximizing the efficiency of its use to produce a crop will be paramount. What, then, are the possibilities of increasing the dryland crop production without further inputs of water, that is, what are the possibilities of increasing the rainfall-use efficiency of dryland crops? (Schlegel *et al*., 2017). In the subtropical, dryland crops can be grown in the warm summer (rainy) season, and in the cooler dry (post-rainy) season if the water-holding capacity of the soil is sufficient to enable the crop growth (Liu *et al*., 2015). High temperature in the rainy season ensure rapid crop development, but erratic rainfall can lead to water shortage, particularly on shallow or coarse-textured soils (Ibrahim *et al*., 2015). The periods of limited water availability can occur any time during the crop growth. While Araus *et al*. (2003) argued that genetic improvements are likely to bring the greatest increase in yield, and hence rainfall-use efficiency, the role of soil management practices to increase yield in the past and in the future need not be overlooked.

Mitigatory strategies to the water crisis have been adopted in production of small grain crops such as millet and sorghum that tolerate drought (Schlegel *et al*., 2017). The sorghum and millet have been noted as staple food grains in many semi-arid, particularly in sub-Saharan Africa and the Mediterranean due to their good adaptation to hard environment and their good yield of production (Sharma *et al*., 2002; Colecchia *et al*., 2017). Taylor *et al*. (2006) described sorghum and millet as generally the most drought-tolerant cereal grain crops that require little input during growth. The semi-arid tropics are characterized by unpredictable weather calamities, limited and erratic rainfall, and nutrient-poor soils and has a plethora of agricultural constraints (Maqbool *et al*., 2001). In this regards, Rinaldi *et al*. (2017) noted an urgent need to focus on improving crops relevant to the smallholder farmers and poor consumers in the semi-arid tropics. Soil management strategies to improve rainfall-use efficiency in drier environments one way to achieve this goal.

Conservation tillage, where minimum tillage or no-tillage is practiced, leaving about one-third of soil covered with residues after planting, is being adopted worldwide (Hatfield, 2011). The effects conservation tillage together with returning crop residues on soil-crop water relations may be over-simplified and the science behind the practice is not given much attention in many researches. Turning the soil so-often as in the case of conventional tillage, increases carbon mineralization into the atmosphere thereby causing global warming. Organic matter improves the structure of the soil and thus the ability of the soil to contain water in its profile. The crop residues left on the soil surface in the conservation tillage reduces water evaporation (Hatfield *et al*., 2001), increase water infiltration (Franzluebbers, 2004), enhance high soil water storage (Ibrahim *et al*., 2015) and reduce rates of soil erosion (Hatfield *et al*., 2001). In another research, Li *et al*. (2015), observed that there were no significant differences in saturated hydraulic conductivity between tilled and non-tilled soil layers but did not report on water storage and crop water use. Payne *et al.* (2000) predicted yield response to precipitation and heat stress but also overlooked on the measured soil moisture and crop water use efficiency (WUE).

The literature on WUE and soil tillage and residue management practices highlighted many options to increase WUE (Hatfield *et al.*, 2001). Among these options were practices that affected water availability and nutrient management practices that increased the nutrient availability to the crop. More importantly, the ability of organic mulch in improving soil aggregation and soil hydraulic properties conserving more rainfall in the soil profile (Ibrahim *et al.*, 2015). However, proving soil surface cover alone was insufficient to maintain high moisture levels under semi-arid conditions (Efthimiadu *et al.*, 2010) as water infiltration may be impeded by soil crusts. Hence, coupling the mulch together with tillage may give improved soil water storage capacity and WUE. Tillage creates changes in the soil surface that break apart the surface soil layers, including soil crusts, leading to an initial increase in the rate of water infiltration and ultimately the increase in soil water storage.

Disturbing the soil surface may cause an increased soil water evaporation if not mulched. The effects of conservation tillage on crop yields and soil physio-chemical properties in the tropics has been evaluated by many researchers and generally agreed that no-till or reduced tillage, produced a higher soil water content and crop yield than conventional tillage (Li *et al.*, 2015; Wang *et al.*, 2011). However, the effects of crop residues retention under these tillage practices on the soil properties are still debatable, especially on short-term experiments (Li *et al.*, 2015). Efthimiadu *et al.* (2010), showed that soil water evaporation occurred from the soil surface until a very thin crust of dry soil was formed and removed the pathway for water exchange to the atmosphere. Removing the crust will increase evaporation because the tillage moves moist soil up to the surface where drying losses are increased. Li *et al.* (2015) showed that disturbing the soil surface with tillage increased soil water evaporation rates compared to untilled areas. Suggesting that changes in WUE are directly affected by covering the soil surface with residue or mulch (Hatfield *et al.*, 2001). Mulching modifies the soil water evaporation through the reduction of soil temperature, impeding water vapour diffusion, absorption of water vapour on the mulch tissue, and decreasing the wind speed gradient at the soil surface-atmosphere interface (Sharma *et al.*, 2002).

Traditionally, about 70% of precipitation falls between October and February in Zimbabwe but has since shifted in the past decade (Parwada *et al.*, 2016). Most rainfall has been received from mid-February to late April; therefore early planted (planted in October) crops mature under increasing drought and heat stresses. Under these conditions, agronomic practices that increase WUE are important to avoid yield reduction. The standard tillage regimes in Zimbabwe is conventional, which leaves little or no surface residue to prevent soil erosion or curb evaporation. About 70% of Zimbabwe's 13.5 million people live in the communal areas (CAs) and approximately three-quarters of the CAs are located in marginal areas (Agro-Ecological regions IV & V) that receive low and erratic rainfall (Mukuvaro *et al.*, 2017). Small grain cereal crops that are drought tolerant such as millet and sorghum are commonly grown in these marginalized areas, however with low yield. The sorghum yield is ranging from 0.4 to 0.5 t/ha on average in the CAs. The low yields are attributed to the prevalence of drought, high variation in amount and distribution of rainfall, use of traditional and unimproved varieties (Parwada *et al.*, 2016). In addition, much of the rainfall in the marginal areas of Zimbabwe i.e natural regions IV & V forms runoff leading to soil degradation hence increase the moisture constraints in these semi-arid areas. Therefore they are needy to improve soil hydrological properties that increase efficient use of the limited and variable rainfall aiming at improving food security and to curbing land degradation.

There is little information on water use efficiency under different soil management practices in dryland cropping under semi-arid conditions. This information is crucial to understanding the underlying processes and formulation of sound agronomic decisions. The objectives of this study were to quantify the effects of different soil management practices on soil water storage, WUE, grain yield and harvest index of dryland sorghum crop. We hypothesized that soil tillage option alone without surface cover does not improve crop water use efficiency.

Material and Methods

Study site

The study carried out on a farmer's field in Muzokomba, a communal area of Zimbabwe (19°34 – 19°38'S: 31°57– 31°63'E) between October 2014 and May 2017. The Muzokomba area lies in the Zimbabwean Lowveld (> 800 m altitude) and is an extensive crop-livestock production area in the agro-ecology region V, receiving rainfall between 300 to 450 mm year^{-1} and frequently experience severe droughts (Table 1). The field was under mixed cropping of millet, cowpeas, pumpkins and sweet sorghum prior to the start (2014) of the experiment. The soils in the Muzokomba area are predominantly coarse sands, with pockets of sandy loams to sandy clay loams that can be classified as Lixisols (IUSS Working Group WRB. 2015). The 2014/15 received above normal rainfall of 550 mm per year, whereas in 2015/16 and 2016/17, the area received below normal rainfall of 380 per year.

Table 1. The Zimbabwe-Agro-Ecological Regions

Agro-ecological region (NR)	Characteristics
NR I	Reliable rainfall (>900mm/year) at 1700 m or 1000 mm/year at low altitude
NR II	750-1000 mm/year confined to summer season
NR III	650-800 mm/year
NR IV	Unreliable rainfall of 450-650 mm/year
NR V	Erratic rainfall of 300-450 mm/year

Adapted from smallholder Horticulture in Zimbabwe, edited by Jackson, Turner and Matanda, 1997

Experimental design

Field experiments were set up in 2014/15, 2015/16 and 2016/17 growing seasons. A split plot laid in a completely randomized block design with three replicates was used. Tillage was the main plot factor and the crop residual management was the subplot factor. Soil tillage practices [conventional tillage (CT), minimum tillage (MT), MT × residue retention (RT) and CT × residue retention (RT)] were the blocking factors. Macia, a Seedco, Zimbabwe sorghum variety was used in this study as it is the most commonly grown variety in the study area due to its earliness to maturity. The sorghum variety is an early maturing that takes about 110 days to maturity in the lowveld (below 800 m altitude). The study involved 3 consecutive sorghum crops in the 2014/15, 2015/16 and 2016/17 at the same site. The sorghum was planted at a seed rate of 10 kg ha^{-1} in 0.75 rows in gross plots of 6 rows 0.75 m × 10 m = 45 m^2 and sample area of 4 rows 0.75 m × 4 summing to a total area of 2 m^2. Thinning was done at 2 weeks after emergence. A basal fertilizer that provides macronutrients in the ratio of 8%N: 14%P: 7%K was applied at a rate of 400 kg ha^{-1} and 100 kg ha^{-1} ammonium nitrate (34.5%N) was applied as topdressing at 4 weeks after planting (Arex 2000-4) and the experiments were under rainfed conditions.

Soil sampling and analysis

Twelve soil samples were randomly taken at 10 cm depth intervals up-to 30 cm (0-10, 10-20 and 20-30 cm) from the whole experimental site (144 m^2) using a graduated auger. The soil was then analyzed for primary particle size distribution and total soil organic carbon (SOC). The primary particle size distribution was determined by the hydrometer method as described by Okalebo *et al.* (2000) and total SOC through the wet acid digestion Walkley-Black method (Nelson and Sommers, 1996).

Planting

The planting was done after receiving the first effective rainfalls in each season; the effective rainfalls were determined using the Farmwest equation (Makuvaro *et al.*, 2017) as follows:

$$Effective\ rainfall\ (mm) = [(Received\ rainfall\ (mm) - 5)] \times 0.75 \quad \text{Eq. 1}$$

Land preparation of the plots was done a week before planting in each season. Aboveground biomass (minus the grain) was manually returned to the MT × RT and CT × RT plots after harvest, whereas all the aboveground biomass was removed in the CT and MT plots. The complete crop removal of residues is a standard practice adopted by farmers in the Muzokomba area. The non-grain biomass is used as a livestock feed during winter periods and burnt during land preparation. The whole plots for CT and CT × RT were dug to a depth of 23 cm, while soil disturbance was done only at the planting stations in the MT and MT × RT plots. The sorghum (*Sorghum bicolor*) was sown in October (early in 2014/15 and late October in 2015/16 and 2016/17 cropping seasons)

Data collection

Grain yield

Grain yield was determined at maturity stage from plants harvested from 0.5 m^2 sample areas. The grain yield was corrected for the standard humidity of 14.5 and was transformed into kg ha^{-1} (Unkovich *et al.*, 2010).

Harvest index

The harvest index (HI) was defined as the ratio of grain yield X and the above-ground biomass at maturity Y :

$$HI = \frac{X}{Y} \quad \text{Eq. 2}$$

Where $Y = X + S$ and S was the straw weight at maturity of the sorghum.

Water use efficiency (WUE)

In this study, we divided the sorghum growth stages after planting (AP) into nine as: emergency stage (1 week AP), collar of 3rd leaf visible (2 weeks AP), collar of the 5th leaf visible (3 weeks AP), growing point of differentiation (4 weeks AP), flag leaf visible in whorl (6 weeks AP), boot stage (7 weeks AP), half-bloom stage (9 weeks AP), soft dough (10 weeks AP), hard dough (12 weeks AP) and the physiological maturity stage (14 weeks AP) (http://glasscock.agrilife.org/files/2015/05/Sorghum-Growth-and-Development.pdf).

Soil moisture analysis

The volumetric water content (θv, v/v %), in the soil layers (0-10, 10-20 & 20-30 cm) was determined at each growth stage of the sorghum crop in 2014/15, 2015/16 and 2016/17 and at crop maturity in February 2015, 2016 and 2017 using a calibrated neutron probe. The soil water in the soil layers was expressed in mm using the following calculation:

$$Soil\ water\ storage = \frac{[\theta v\ (\%) \times depth\ (mm)]}{100} \quad \text{Eq. 3}$$

Change of storage water capacity was then calculated as:

$$Change\ in\ storage\ water\ capacity\ (\%) = \frac{SWC\ at\ time\ 2 - SWC\ at\ time\ 1}{SWC\ at\ time\ 1} \times 100 \quad \text{Eq. 4}$$

Soil moisture data at each growth period of the sorghum crops during the two seasons were used to calculate the field water consumption (mm) using a modified equation by Zhang *et al.* (2015) as follows:

$$ET_{1-i} = \sum_{i=1}^{n} R_i\ L_i(l_{i1} - l_{i2}) + P_0 + I + S,\ (i = 1, 2, \ldots, n) \quad \text{Eq. 5}$$

Where ET_{1-i} was ; the water consumption of the ith soil layer number, n total soil layers, R_i soil dry density in the ith layer of soil; L_i soil thickness in the ith layer of soil; l_{i1} and l_{i2} water content at first and last stages of the period in the ith layer of soil, calculated as percentage accounting for dry density, respectively; P_0 effective rainfall; I irrigation during the period; S supplementary ground water capacity during the period (deep percolation and capillarity rise). We ignored I and S because we did not irrigate. The ET_a was the sum of ET_{1-i} (0-30 cm) calculated in Eqn. 4 and the WUE calculated as follows:

$$WUE = \frac{Y}{ET_a} \quad \text{Eq. 6}$$

Where WUE means water use efficiency (kg ha^{-1} mm^{-1}), Y is crop yield (kg ha^{-1}) and ET_a is the actual water consumption during the growth period (mm) (i.e. the sum of water consumption for each sorghum growth stages).

Statistical analyses

The observations were independent of each other, data normally distributed and followed homoscedasticity thus the analysis of variance (ANOVA) was run to compare treatment means among the soil moisture storage, grain yield, and water use efficiency. Means were separated using the Tukey test ($p < 0.05$). Pair-wise correlations between water use efficiency by the sorghum crops under the various soil tillage and residue management practices and the measured soil properties were done. All data were analyzed using JMP version 11.0.0 statistical software (SAS Institute, Inc., Cary, NC, USA, 2010).

Results and Discussion

The amount and distribution of received rainfall in the Muzokomba area varied significantly ($P < 0.05$) across the three growing seasons. The total amount of rainfall was low at the start (October to January) of the seasons but increased from February to May (Figure 1). Accumulated rainfall during 2014/15, 2015/16 and 2016/17 growing seasons were 361, 308 and 412 mm, respectively (Figure 1), corresponding to 28.2, 28.2 and 16 % of the rainfall used for sorghum growth (i.e. October to February since the Macia variety matures at 110 days AP). The remainder of the rainfall was lost through drainage, runoff and storage below the root system. According to Turner (2004) an arid, normal and wet year have rainfall amounts of 250, 400 and 550 mm, respectively during the crop growing season. Based on this classification all the three growing seasons were dry since most of the total rainfall was received from February to May in each season but the crop had already matured therefore the water requirement was low as the crop had approached the senescence (Figure 1). Therefore, the rainfall distributional patterns varied significantly ($P < 0.05$) over the three cropping seasons (Figure 1).

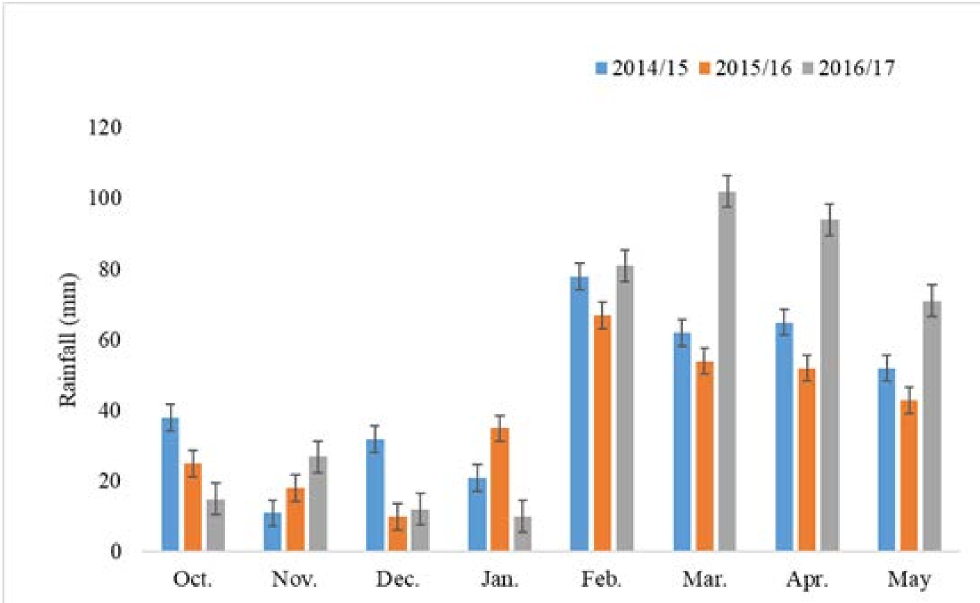

Figure 1: Monthly rainfall (mm) distribution in the Muzokomba area during the 2014/15, 2015/16 and 2016/17

Based on the average total rainfall received per month, December and March were the driest and wettest months respectively (Figure 1). Considering the trend of rainfall pattern above, farmers may be recommended to plant sorghum starting in January if they want to avoid drought stress.
The soil had higher amounts of sand content (%) than clay (%). The uppermost (0-10 cm) soil layer had the highest percentage of sand than clay particles (Table 2).

Table 2. The mean soil texture (mm) (%) in the soil of the Muzokomba area.

Sampling depth (cm)	Sand (0.06-2)	Silt (0.002-0.06)	Clay (<0.002)
0-10	55.0 (0.6)	45.1 (1.1)	4.9 (1.3)
10-20	47.4 (1.2)	46.4 (0.5)	6.2 (0.7)
20-30	41.0 (0.9)	54.8 (0.8)	4.2 (0.4)

The number after the means indicates (± se)

Sand (%) was decreasing with depth while clay particles showed to increase up-to-the 10-20 cm layer but were decreasing in the 20-30 cm layer (Table 2).
Soil organic carbon (SOC) content (%) was significantly ($P < 0.05$) different at the beginning (2014) and end (2016) (Table 3). Soil organic carbon was significantly decreasing in both the CT and MT but increased under MT × RT and CT × RT.

Table 3. The initial (in 2014) and last (in 2016) mean soil organic carbon (SOC) content (%) in the Muzokomba area soil.

Soil management practices	**Soil depth (cm)**	**2014**	**2016**
CT	0-10	1.90^{d}	0.52^{e}
	10-20	1.81^{c}	1.31^{c}
	20-30	0.84^{e}	0.61^{e}
MT	0-10	1.90^{d}	1.72^{d}
	10-20	1.80^{c}	2.70^{a}
	20-30	0.84^{e}	0.71^{e}
MT × RT	0-10	1.90^{d}	5.80^{a}

	10-20	1.81^{c}	4.01^{b}
	20-30	0.84^{e}	3.00^{c}
CT × RT	0-10	1.90^{d}	3.21^{c}
	10-20	1.81^{c}	1.80^{b}
	20-30	0.84^{e}	1.21^{c}

Means were separated using F-protected $LSD_{0.05}$. Means followed by the same superscript were not significantly (P< .05) different.

The MT × RT and CT had the highest and lowest SOC content at the end (2016) of the study, respectively (Table 3). Returning of crop residues had raised the SOC significantly in all the three soil layers whereas soil tillage without returning crop residue did decrease the SOC content (%).

There was no significant (P < 0.05) difference in sorghum yields under the conventional tillage (CT), however, they were differences in the yielding of the sorghum crop under the minimum tillage (MT) (Figure 2). There was no significant difference in yields in the 2014/15 and 2015/16 though a significant increase was observed in 2016/17 season under the MT (Figure 2**a**). The grain yield (t/ha) was higher in the 2014/15 than in the two succeeding seasons (2015/16 and 2016/17) under the conventional tillage with retained residues (CT × RT) (Figure 2**a**). The tillage at the start of the experiment provided a fine tilth for easy water infiltration, root growth and water utilization by the crop. However, repeated tillage of the soil resulted to loss of structure thereby reduced water use efficiency by the crop even with retained residues hence the lower yield (Figure 2a). The sorghum grain yields were significantly (P < 0.05) lower during the two preceding seasons (2014/15 and 2015/16) than in third season (2016/17) under the minimum tillage with retained residues (MT × RT) (Figure 2**a**).

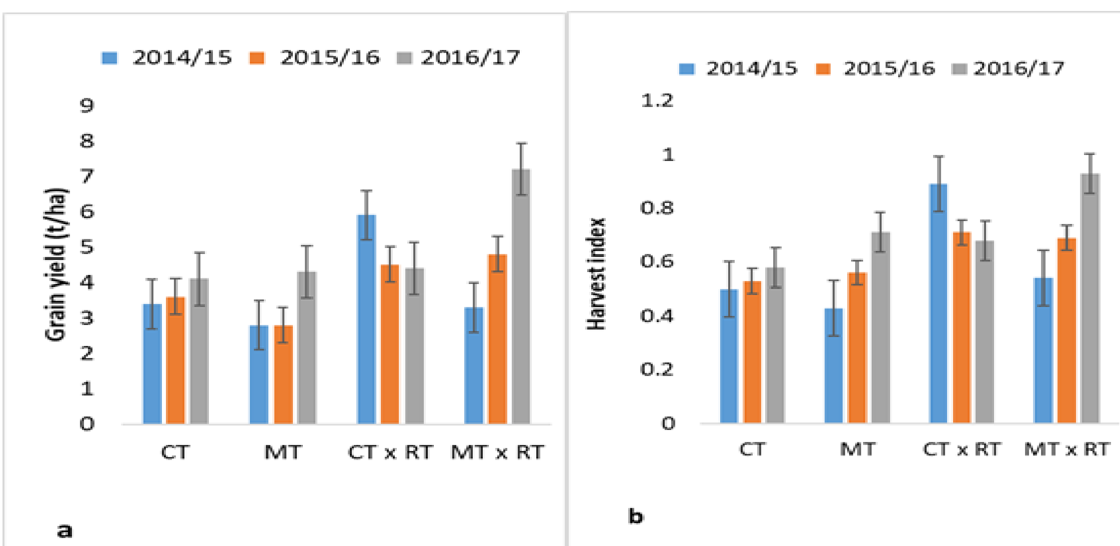

Figure 2. Effects of soil tillage and residue management practices on mean grain yield (t/ha) (a) and harvest index (b) during the three successive sorghum cropping in 2014/15, 2015/16 and 2016/17

There was significant (P<0.05) increase of grain yield from the first (2014/15) to the third cropping season under MT and MT × RT (Figure 2**a**).

There was no significant (P < 0.05) difference in the harvest index of sorghum crop under the conventional tillage (CT). No significant difference in the harvest index was observed in 2014/15 and 2015/16 in 2016/17 season, but there was a significant (P <0.05) increase of the harvest index under the MT (Figure 2**b**). Grain yield increased by 45% and 33% in the second and third seasons respectively under the MT × RT but a 25% decrease was observed from the initial to the third season under the CT × RT.

Higher harvest index ratios were noted for the 2014/15 than during the two succeeding seasons (2015/16 and 2016/17) under the conventional tillage with retention residues (CT × RT) (Figure 2**b**). The harvest index was significantly ($P < 0.05$) lower in the 2014/15 and 2015/16 seasons than in 2016/17 under the minimum tillage with retained residues (MT × RT) (Figure 2**b**). The grain yield was lower in the first and second season (2014/15 and 2015/16) than the third season (2016/17) may be due to higher weed competition and water loss through percolation.

The soils were sandy and had low (< 2 %) soil organic carbon content (Table 3) suggesting that there were poorly aggregated hence high water loss through evaporation and percolation. However, as the soil organic matter buildup and weed suppression effects from the retained crop residues in the second and third growing season. The retained residues increased the soil organic matter content of sandy soil thereby increasing its water holding capacity that resulted to higher yields. The results agreed to Efthimiadu *et al.* (2010) who also found low in yield under no-till systems in early years of implementing the no-till due to increased weed pressure. A combination of low soil surface cover, reduce water infiltration resulting from burning of crop residues during land preparation, and weed competition led to reduced grain yield and WUE under the MT and CT. Large amounts of surface organic matter residues from the mulch has been shown to increase water infiltration and reduced evaporation, resulting in increased soil water storage (Hatfield *et al.*, 2001; Li *et al.*, 2015). The retained crop residues could have improved the soil-water storage hence a positive increase in WUE, grain yield and harvest index in the MT × RT and CT × RT.

Grain yield and harvest index were decreasing with time under the CT × RT but to increase with time under the MT × RT (Figure 2). Minimum tillage with retained residues increased soil organic matter (Li *et al.*, 2015), decreased surface runoff and increased soil water content and decreased nitrous oxide emissions (Drury *et al.*, 2012). However, it was reported that the MT × RT reduced soil infiltration and increased surface bulk density (Wang *et al.*, 2011).

Change of soil water storage was significantly ($P < 0.0$) varying across the period of the crop cycle, but the soil depth water distribution patterns were similar in all the three growing seasons. Generally, changes in soil water storage varied more in the uppermost soil layer (0-10 cm) than in lower soil layers (10-20 cm, 20-30 cm) (Table 4). The change of soil water storage was continuously fluctuating and the uppermost soil layer (0-10 cm) had significantly ($P < 0.05$) the greatest changes (%) for most periods of the crop cycle except in the 2016/17 under the MT, MT × RT and CT × RT (Table 4). There was no significant ($P < 0.05$) difference on soil water storage changes in the MT × RT and CT × RT during the 2014/15 crop extraction period but was significantly ($P < 0.05$) lower in the MT × RT than CT × RT in the subsequent periods of crop cycle (Table 4).

Table 4. Effects of soil tillage and residue management practices on percentage (%) changes in soil water storage (mm) with depth (cm) during the cropping cycle in 2014/15, 2015/16 and 2016/17, due to crop consumption and fallow accumulation.

Period of the crop cycle	Soil depth (cm)	CT	MT	MT × RT	CT× RT	P-value
2014/15 Crop water use from sowing to harvest	0-10	37.0^{a}	35.9^{a}	21.1^{c}	19.1^{c}	0.005
	10-20	25.8^{b}	27.2^{b}	12.8^{d}	13.5^{d}	0.001
	20-30	19.6^{c}	18.1^{c}	15.2^{d}	10.6^{d}	< 0.001
2015 Fallow accumulation (from harvesting to sowing)	0-10	34.6^{a}	35.5^{a}	22.2^{c}	27.4^{b}	> 0.05
	10-20	20.9^{a}	10.2^{e}	5.9^{f}	11.7^{e}	0.003
	20-30	11.5^{a}	4.6^{f}	3.8^{f}	4.1^{f}	< 0,001

2015/16 Crop water use (from sowing to harvest)	0-10	19.4^{a}	11.7^{b}	4.1^{c}	4.8^{c}	0.002
	10-20	15.6^{b}	10.2^{b}	3.2^{c}	3.7^{c}	0.004
	20-30	4.1^{c}	4.0^{c}	1.5^{d}	1.3^{d}	< 0.001
2016 Fallow accumulation (from harvesting to sowing)	0-10	30.5^{a}	36.1^{a}	10.1^{b}	14.4^{b}	0.05
	10-20	16.1^{b}	10.1^{c}	11.0^{c}	10.7^{c}	0.02
	20-30	10.7^{c}	9.7^{c}	6.2^{d}	5.1^{d}	0.003
2016/17 Crop water use (from sowing to harvest)	0-10	25.1^{a}	18.1^{c}	7.6^{e}	10.8^{d}	0.004
	10-20	19.1^{b}	17.4^{c}	5.8^{e}	9.2^{d}	0.001
	20-30	13.3^{c}	16.1^{c}	4.6^{e}	11.2^{d}	0.03

Percentage of change (%) values per period of the crop cycle with the same superscript were not significantly ($P < 0.05$) different.

In the 2016/17 crop extraction (from sowing to harvest), the changes (%) in soil water storage was significantly ($P < 0.05$) constant in the MT, MT × RT and CT × RT at all soil depths, however, was observed to change across the periods of crop cycle in the following order; MT > CT × RT > MT × RT (Table 4). The sharp changes in soil water storage in the 0- 10 cm soil layer can be attributed to drainage out and high evaporation caused by the high sand (%) particles found in the layer (Table 2). The returned crop residues in the MT × RT and CT × RT helped to conserve soil moisture during both the cropping and fallowing periods, therefore, the changes in soil water storage was decreasing with the time form the start of the experiment. In general, higher changes in soil water storage were found in MT and CT during the crop cycle and time interval between two successive crops compared to the soil management with retained residues.

There were no significant ($P < 0.05$) in water use efficiency (kg/ha/mm) by the sorghum crop under the CT and MT soil management practices. The WUE by the sorghum crops was significantly lower in soil tillage and residue management practices without (CT and MT) than with (MT × RT and CT × RT) residues retention in the three growing seasons (Figure 3). The WUE by the sorghum crop was significantly ($P < 0.05$) increasing from (2014/15) to (2016/17) season in the MT × RT but was decreasing from the 2014/15 season in the CT × RT (Figure 3).

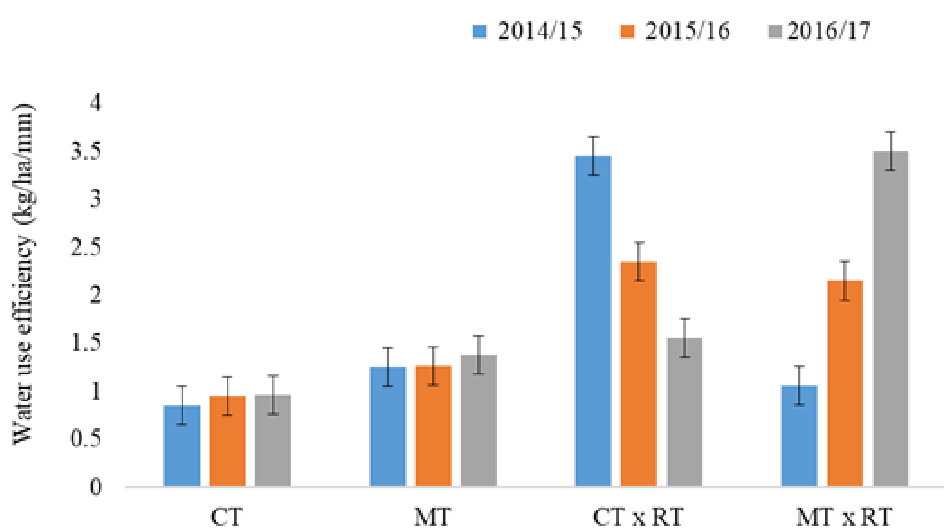

Figure 3: Effect of soil management practice on the water use efficiency (kg/ha/mm) by the sorghum crops during the 2014/15, 2015/16 and 2016/17.

Water use efficiency by the crops was significantly (P <0.05) the same in the soil tillage systems without residue retention, and under the MT × RT in the first (2014/15) season (Figure 3). There was a significant increase by about 70% of WUE by the sorghum crops from the initial to last season in the MT × RT, whereas a 55% decrease in the WUE was observed in the CT × RT during the three cropping seasons.

The water use efficiency (WUE) was significantly (P < 0.05) and positively correlated to soil organic carbon (SOC) content, grain yield, harvest index and soil water storage (Table 5). The SOC and the sand particle content in the soil layers had a significantly (P < 0.05) negative correlation (Table 5).

Table 5. The Person's coefficient values showing relationship between water use efficiency (WUE) and the measured soil properties

	WUE	SOC	Sand	Clay	Silt	SWS	GY
SOC	0.78**						
Sand	-0.51**	-0.71**					
Clay	0.05	0.34	0.01				
Silt	0.08	0.06	0.43	0.02			
SWS	0.61**	0.76**	-0.71**	0.14	-0.41		
GY	0.70**	0.54**	-0.21	0.06	-0.32	0.77**	
HI	0.85**	0.62**	-0.33	0.12	-0.11	0.70**	0.79**

Note: SWS = soil water storage, GY = grain yield and HI = harvest index, values with ** were significant at P <.05

The significant positive increase of WUE, grain yield, harvest index and water storage noted under tillage practices with returned residues (CT × RT & MT × RT) could be due to the increase in soil organic matter. Soil amendments such as mulching and manure have been successfully applied to the soil, supplying it with nutrients for crop uptake, enhancing the nutrient cycle and improving soil moisture content (Wang *et al.*, 2011). The reduction in the measured parameter with time under the CT × RT could be due to the continuous breaking of soil aggregates and exposing the organic matter to microbial decomposition, thereby fast losing the nutrients through leaching and carbon mineralization. Suggesting the negative effects of high frequent disturbance of the sandy soils.

In dryland conditions, the major challenge is to modify the soil properties that enhance WUE and grain yield and protect the soil resource from degradation. Grain yield (GY) and harvest index (HI) were highly and positively correlated with WUE (Table 5) signifying that improvements in the grain yield and harvest index increases WUE as the evapotranspiration (ET) will be reduced. In our study, WUE was influenced by the grain yield, harvest index and the soil water depletion, and growing season precipitation (Eq. [4]). Soil management practices that can change the value of these variables can change the values of WUE also. Among these variables, the amount of rainfall cannot be manipulated but its storage in the soil and use can be altered. Soil water depletion, a component of growing season evapotranspiration, was different among the soil management practices and across the period of crop cycle at all soil depth except the crop extraction during the 2016/17 season (Table 4).

It was not possible to estimate how much water was lost through soil evaporation and through the plant (transpiration) using data from this study. Consequently, we were unable to determine how different the soil tillage and residue management practices influenced soil water evaporation and transpiration. However, the soil management practices that reduce soil evaporation and increase transpiration will likely increase grain yield, harvest index and WUE. Hatfield *et al.* (2001) showed that there was a strong and positive correlation between transpiration and crop productivity. In addition, growing conditions that are favorable for plant growth will likely increase grain yield, harvest index and, therefore, WUE. The most practical way of increasing transpiration and reducing soil water evaporation is to increase soil surface cover through mulching (Hatfield, 2011). Crop residues, left on the surface, not only reduce evaporation but also increased water infiltration. This could explain the highest changes in soil water storage under the MT and CT, when the soil surfaces were not covered (Table 4). In our study, the MT × RT stored the highest amount of water during both the cropping seasons and fallowing periods. Removal and burning of crop residues during land preparation in the MT and CT left about 1% surface cover that was not sufficient to curb soil water evaporation, particularly in August and September when evaporation demand was highest.

Conclusion and Recommendations

The soil tillage and crop residue management significantly affected on sorghum grain yield, harvest index, soil water storage and water use efficiency. The conventional tillage with returned residues had an instant but short-term positive effects on the measured parameters suggesting that continuous convectional tillage is not beneficial even with returned residues. Returning crop residues on minimum tillage (MT × RT) had gradual and long-term effects on the measured soil and crop parameters, proving that the MT × RT is a sustainable practice to improve soil water storage and WUE under the dryland conditions of Zimbabwe. We observed higher WUE under returned crop residues than in the farmer's traditional practices of overall ploughing or disturbing only the soil surface without residues. We hope further work to look at the interactions between soil water conservation techniques and soil fertility management practices.

Conflict of interest

They are no conflict of interests regarding the publication of this paper.

References

1. Araus, J.L., Bort, J., Steduto, P., Villegas, D., & Royo, C. (2003). Breeding cereals for Mediterranean conditions: ecophysiological clues for biotechnology application. Annals of Applied Biology. 142, 129– 141.
2. Colecchia, S.A., De Vita, P., & Rinaldi, M. (2015). Effects of Tillage Systems in Durum Wheat under Rainfed Mediterranean Conditions. Cereal Research Communications, 43: 704–716.
3. Efthimiadou, A., Bilalis, D., Karkanis, A., & Froud-Williams, B. (2010). Combined organic/inorganic fertilization enhances soil quality and increased yield, photosynthesis and sustainability of sweet maize crop. Australian Journal of Crop Science. 4, 722-729.
4. Franzluebbers, A.J. (2004). Tillage and residue management effects on soil organic matter. p. 227–268. In F. Magdoff and R.R. Weil (ed.) Soil organic matter in sustainable agriculture. CRC Press, New York.
5. Hatfield, J.L., Sauer, T.J., & Prueger, J.H. (2001). Managing soils to archive greater water use efficiency: A review. Agron. J. 93:271–280.
6. Hatfield, L. (2011). Soil Management for Increasing Water Use Efficiency in Field Crops under Changing Climates. Soil Management: Building a Stable Base for Agriculture. 161-174. DOI:10.2136/2011.
7. Ibrahim, A., Abaidoo, R.C., Fatondji, D., & Opoku, A. (2015). Hill placement of manure and fertilizer micro-dosing improves yield and water use efficiency in the Sahelian low input millet-based cropping system. Field Crops Research. 180, 29-36.

8. IUSS Working Group WRB. (2015). World Reference Base for Soil Resources 2014, update 2015, International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.
9. Jackson, J.E., Turner, A.D., & Matanda, M.L. (1997). Smallholder Horticulture in Zimbabwe, University of Zimbabwe Publications, Harare, Zimbabwe.
10. Li, S.X., Wang, Z.H., Li, S.Q., & Gao, Y.J. (2015). Effect of nitrogen fertilization under plastic mulched and non-plastic mulched conditions on water use by maize plants in dryland areas of China. Agricultural Water Management. 162, 15-32.
11. Makuvaro, V., Walker, S., Munodawafa, A., Chagonda, I., Masere, P., Murewi, C., & Mubaya, C. (2017). Constraints to crop production and adaptation strategies of smallholder farmers in semi-arid Central and Western Zimbabwe. African Crop Science Journal. 25, 221 – 235.
12. Maqbool, S.B., Devi, P., & Sticklen, M. (2001). Biotechnology: genetic improvement of sorghum (Sorghum bicolour). In vitro Cell Developmental Biology- Plant. 37,504-515.
13. Nelson, D.W., & Sommers, L.E. (1996). Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis, Part 2, 2nd ed., Page et al A.L Ed. Agronomy. 9: 961-1010. Am. Soc. Of Agron. Inc. Madison, WI.
14. Okalebo, J.B., Gathua. K.W., & Woomer, P.L. (2000). Laboratory Methods of Soil and Plant Analysis: A Working Manual. TSBF-KARI-UNESCO, Nairobi, Kenya.
15. Parwada, C., Karavina, C., Kamota, A., Mandumbu, R., & Nyemba, S. (2016). Evaluation of seasonal rainfall changes on the growth performance of Vigna unguiculta (cowpeas) in Zimbabwe. Academia Journal of Agricultural Research. 4: 067-071.
16. Payne, W.A., Rasmussen, P.E., Chen, C., Goller, R., & Ramig, R.E. (2000). Precipitation, Temperature and Tillage Effects upon Productivity of a Winter Wheat–Dry Pea Rotation. Agron. J. 92:933–937.
17. Rinaldi, M., Scalcione, E., Perniola, M., Maddaluno, C., & Garofalo, P. (2017). Soil tillage and residues management in wheat continuous cropping in Southern Italy: A model application for agronomic and soil fertility assessment. Computers and Electronics in Agriculture. 140: 77–87.
18. SAS Institute Inc. (2010). SAS campus drive, Cary, North Carolina, United States.
19. Schlegel, A.J., Assefa, A., Haag, L.A., Thompson, C.R., & Stone, L.R. (2017). Long-Term Tillage on Yield and Water Use of Grain Sorghum and Winter Wheat. Agronomy Journal - Crop Economics, Production & Management. 110: 269-280.
20. Sharma, K.K., Crouch, J. H., Seetharama N., & Hash, C.T. (2002). Applications of biotechnology for crop improvement: Prospects and Constraints. In vitro Cell Developmental Biology-Plant 163: 381-395.
21. Tadele, Z. (2017). Raising Crop Productivity in Africa through Intensification. Agronomy. 7, 22; DOI:10.3390/agronomy7010022.
22. Taylor, J.N., Schober, T.J., & Bean, S.R. (2006). Novel food and non-food uses for sorghum and millets. Cereal Science. 44: 252–271.
23. Troccoli, A., Maddaluno, C., Mucci, M., Russo, M., & Rinaldi, M. (2015). Is it appropriate to support the farmers for adopting conservation agriculture? Economic and environmental impact assessment. Italian Journal of Agronomy. 10: 661-177.
24. Turner, N.C. (2004). Agronomic options for improving rainfall-use efficiency of crops in dryland farming systems. Journal of Experimental Botany. 55: 407-418.
25. Unkovich, M., Baldock, J., & Forbes, M. (2010). Chapter 5 - Variability in Harvest Index of Grain Crops and Potential Significance for Carbon Accounting: Examples from Australian Agriculture. Advances in Agronomy. 105: 173-219.

26. Wang, J., Liu, W.Z., & Dang, T.H. (2011). Responses of soil water balance and precipitation storage efficiency to increased fertilizer application in winter wheat. Plant Soil. 347, 41-51.
27. Zhang, J., Ren, W., An, P., Pan, Z., Wang, L., Dong, Z., He, D., Yang, J., Pan, S., & Tian, H. (2015). Responses of Crop Water Use Efficiency to Climate Change and Agronomic Measures in the Semiarid Area of Northern China. PLoS ONE 10(9): e0137409.