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SOIL & CROP SCIENCES | RESEARCH ARTICLE

Soil moisture, dryland sorghum (*Sorghum bicolor* L.) growth and grain yield responses to in-field rain water harvesting tillage methods

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Abstract: Dryland Sorghum, which is the fifth most important cereal crop in the world, is grown in Zimbabwe typically as a rain-fed crop in areas receiving low, erratic and highly variable rainfall. A two-season field trial was carried out at Save Experiment Station (20°24′S; 28°29′E) in Zimbabwe to establish soil water storage, selected biometric parameters of dryland grain sorghum responses to in-field rain-water harvesting tillage methods. Deep basin tillage method significantly increased the soil moisture content by 14.6% (62.5 mm); 6.2 % (26.5 mm) above that on the ridges and in furrows of open and closed end tied ridges, respectively. Soil moisture storage in deep basins, on ridges and in furrows of open and closed end tied ridges exceeded that in conventional tillage plots by 98.0 mm (29.8%); 35.5 mm (10.8%) and 69.5 mm (21.1%), respectively. Consequently, sorghum plant biometric growth parameters in deep basin tillage treatments were significantly higher than those in conventional, open- and close-ended tied ridges tillage plots. However, the use of conservation tillage methods where tied end ridges are opened introduces

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PUBLIC INTEREST STATEMENT

The full-service restaurant industry presents an important sector of the Malaysian service industry. Given this sector's contribution to the national exchequer, it is important to understand how the physical and social aspects of Servicescape influence consumer dining experience and post-purchase behavioural intentions. This study investigates the interrelationship between servicescape and behavioural intentions through moderating and mediating effect of perceived crowding and customer satisfaction, respectively. The statistical evidence supported a holistic view of Servicescape has important implications on consumer behaviour in the full-service restaurant context (Malaysia). Managers should incorporate social and physical Servicescape to develop their policies and strategies to appease customers. For instance, managers can manipulate restaurant design, layout, ambient conditions, employees and customer's appearance, and behaviour to influence other consumer's service evaluation and post-purchase behaviour. Similarly, the level of crowdedness can be maintained using different strategies to make the restaurant a busy space to attract and influence the consumption experience of dinners.

homogeneous soil water build-ups in furrows and ridges as those observed in tied end ridges with closed ends. As a consequence, biometric growth parameters of sorghum are not altered by substituting open with closed end tied ridges.

Subjects: Agriculture & Environmental Sciences; Plant & Animal Ecology; Soil Sciences

Keywords: In-field rain water harvesting tillage methods; soil water; sorghum growth; grain yield

1. Introduction

The southern African region relies on subsistence agriculture with little adaptive capacity to climate change (Twomlow et al., 2006). In south-eastern Zimbabwe, grain sorghum plays an important role in food security for the smallholder farmers (Mupangwa et al., 2012; Rockstrom et al., 2009). Grain sorghum is grown typically as a rain fed crop in areas receiving low, erratic and highly variable annual rainfall ranging from 400 to 600 mm (Twomlow et al., 2006). Despite its resilience to dry soil moisture conditions, the production potential of grain sorghum is considerably limited by soil water deficit (Assefa et al., 2010; Bhadha et al., 2016; Rockstrom, 2003a). A medium-to-late maturing sorghum cultivar (maturity within 110 to 130 days) requires approximately 550 mm of water during a growing season (Tolk & Howell, 2001).

In sub-Saharan Africa, intra-season dry spells, which are a common event, have a severe impact on the grain sorghum crop production potential, especially if they coincide with critical stages of crop growth and development (Mupangwa et al., 2012; Tekle & Zemach, 2014). Frequent mid-season droughts considerably reduce the vegetative growth potential of the sorghum crop (Assefa et al., 2010; Tekle & Zemach, 2014). Soil moisture stress under dryland sorghum reduces the rate of cell expansion and, ultimately, cell size and consequently, growth rate, stem elongation, and leaf expansion (Fernandez et al., 2012; Wang et al., 2005). Dryland grain sorghum sensitivity to soil moisture deficit is greater during reproductive stages than during the vegetative stage (Baudron et al., 2011; Rockstrom et al., 2009). Soil moisture stress from boot stage through approximately 10 days after anthesis has been reported to severely affect grain yield of sorghum (Mupangwa et al., 2012). Water stress during reproductive stages can stop the development of pollen and ovules (Bhadha et al., 2016; Tekle & Zemach, 2014), prevent fertilization and induce premature abortion of fertilized ovules (Fernandez et al., 2012).

In order to improve crop production in the marginal rainfall regions of Zimbabwe, farmers have to adopt new tillage technologies that conserve fragile soils (Rockstrom et al., 2009; Wang et al., 2005) and extend the period of water availability to the crop. Dryland sorghum studies in the region have suggested various practices of in-field rain water harvesting and soil water storage methods that can increase water use efficiency, and therefore increase yields and reduce the likelihood of crop failure (Stone & Schlegel, 2006; Twomlow et al., 2006).

While studies on in-field rainwater harvesting in sub-Saharan Africa are extensive and thorough, a limited number of research on the effects of rain water harvesting tillage techniques on soil moisture storage; dryland grain sorghum growth and yield were undertaken in Zimbabwe. Thus, a two-season field experimental study was conducted in order to interrogate the growth and yield response of dryland sorghum transplants to in-field water harvesting tillage methods.

2. Materials and methods

2.1. Site description

The field experiments were conducted during 2016/17 and 2017/18 dryland cropping seasons at Save Valley Experiment Station (20°24′S; 28°29′E, 1340 m above sea level) in Chipinge district of south eastern Zimbabwe (Figure 1). The experimental site is located in Agro-Ecological Region V,

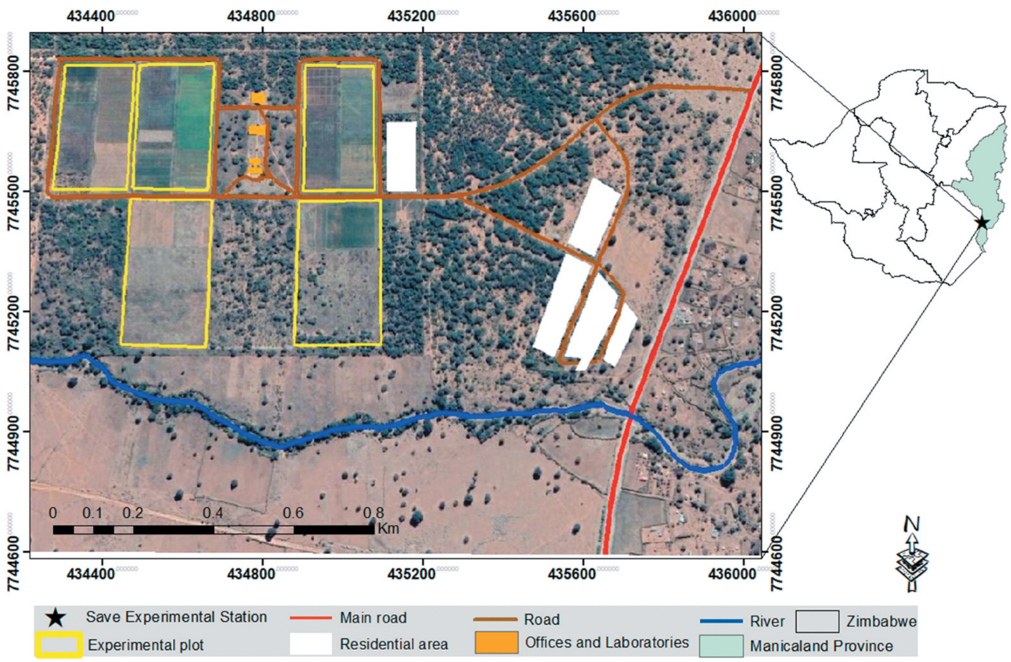


Figure 1. Experimental site location.

which is characterized by mean annual rainfall ranging from 300 to 550 mm and a mean annual temperature of 27°C (Vincent & Thomas, 1960). Rainfall occurs during a single rainy season extending from November to April (Department of Meterological Services, 1981; Mupangwa et al., 2012). The experimental soil is a deeply weathered loamy-sand topsoil over clay-loam subsoil derived from basaltic greenstone and classified as a Chromic-Leptic Cambisol (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012).

2.2. Weather data collection
The rainfall and temperature data were collected from an automatic weather station which was installed at the experimental site.

2.3. Experimental soil characterization
Soil samples were collected randomly prior to planting from a depth of 0–30 cm in a zigzag pattern from the experimental field using soil auger. Composite samples were prepared for determination of the soil physicochemical properties of the experimental site. Soil organic carbon and soil texture were determined by the Walkely and Black (Nelson & Sommers, 1996) and Bouyoucos (1965) hydrometer methods, respectively. Soil pH was analyzed using a digital pH meter (Orion 701, Orion Manufacturing, Ionia, MI, USA). Total N was measured by the Kjeldahl method (Bremner, 1996), while soil bulk density was determined using the core method as described by Blake and Hartge (1986). The soil cores at the experimental site were collected and oven-dried at 105°C (to constant weight) for determination of mean gravimetric water content (Table 1).

3. Land preparation and establishment of field experiments

3.1. Establishment of sorghum-seedling nursery
The field trial was conducted in fixed experimental plots previously under conventional tillage sorghum crop. In the last week of September in 2016 and 2017, two sorghum seedling nursery beds measuring 8.0 m × 4.0 m were prepared by digging soil using hand hoe to a depth of 20 cm and then levelling using a rake. Ridges measuring 15 cm high were established around each nursery bed to avoid surface run-off of irrigation water from the seed beds.

Table 1. Chemical and physical properties of the experimental soil

Soil depth, (cm)	Soil pH (H_2O)	Org-C (%)	N $mgkg^{-1}$	Sand (%)	Clay (%)	Silt (%)	Total porosity (cm^3cm^{-3})	Bulk density (gcm^{-3})	Saturation gravimetric water (gg^{-1})
0–20	7.3	0.92	28.3	34	41	25	0.49	1.36	0.52
20–60	7.6	0.74	20.9	33	50	17	0.44	1.42	0.66
60–100	7.8	0.47	19.2	27	63	10	0.40	1.41	0.70

The area normally receives the first effective rains in the first (early rains) or second (late rains) half of November each year (Department of Meterological Services, 1981). Sorghum-seedling transplanting to the field is usually performed after receiving the first effective rains in November. The sorghum seed planting in the two nursery beds was staggered by a week (7 days) as a measure to reduce the risk of receiving the late effective rains in November leading to late-seedling transplanting. To this effect, the first nursery seed bed was seeded in the first week of October, while the second nursery seed bed was seeded a week later for each year. Uniform seeds of the semi-dwarf sorghum cultivar Macia were treated with a fungicide captan against seed-borne diseases. The sorghum seeds were broadcast liberally on the surface of the nursery beds and buried using a garden trowel to a depth of 2 cm. The seed beds were irrigated to field capacity when necessary until seedling transplanting. Flood irrigation was employed using hydro-fixed tubes with control valves. Seed emergence was recorded between 5 and 10 days in each of the two nursery beds.

3.2. Establishment of experimental field plots

There were 18 experimental plots under six treatments with three replications for each treatment (three blocks) in each of the two seasons. The net plot dimensions were 10.0 m × 4.0 m giving a net area of 720 m^2 under the experimental plots. A straight line was marked out up and down the slope by hand hoe on opposite sides of each of the plots randomly selected for basin tillage in each block. Small pegs were drilled in the soil down the slope of the plots at 90 cm intervals using a measuring stick to mark the inter-row basin spacing. Knots were tied at 60 cm interval along strings called teren ropes to mark the basin in-row spacing. The teren ropes were then securely tied to the pegs on one side of the plot and stretched across the plot to the corresponding pegs on the other side of the plot. Starting at the first knot at one end of the teren rope facing uphill, basins were dug by hand hoe measuring 15 cm long; 15 cm wide and 24 cm deep (deep basin). The excavated soil from the basins was heaped on the downslope side of the basin. Ultimately, the planting basins had spacing of 90 cm by 60 cm.

A mold board plow was used to establish 20 cm contour ridges and the 15 cm deep furrows, which were then modified using the hand hoe to create open- and close-ended tied ridges in the randomly selected plots in each block. The ridge peaks were 90 cm apart. The ridges were laid across the main slope at a grade of 0.4–1% with side slope steepness of 50–60% (Botha et al., 2012; FAO, 1993).

A randomly selected plot in each block was subjected to conventional plowing with a mold board plough and harrowing to produce a fine seedbed that allowed seedlings to be planted on moist soil.

Transplanting of the sorghum seedlings commenced immediately after receiving the first effective rainfall (at least 50 mm) on the 14^{th} and 21^{th} of November for years 2016 and 2017, respectively. The two-week-old seedlings were uprooted in wet soil using a garden trowel and transported to the field plots by trolley. Sowing was done with a hand drill maintaining inter-row spacing of 90 cm and in row spacing of 60 cm after thinning on the flatbed (standard conventional tillage); in deep basins and open and closed end tied ridges with planting in furrows and on ridges. There were three plants per basin after thinning. The indicated plant spacing for the tillage systems resolved into 55 500 plants ha^{-1}.

All treatments, including the control plots, were subjected to a basal fertilizer application of 80 kg ha^{-1} of compound D fertilizer (10% N; 20% P_2O_5;10% K_2O; and 6.5% S). At five weeks after planting, the sorghum test crop in all treatments was subjected to a top dressing application of ammonium nitrate fertilizer (34.5% N) at 200 kg ha^{-1}. During the growing season, all plots were weeded manually at three and six weeks after transplanting.

3.3. Experimental treatments, design and test crop management
A combination of conventional and conservation tillage systems in six treatments were replicated three times in 18 plots in randomized block design. The gradient was the blocking factor. The following treatments were used to test the effect of in-field rainwater harvesting techniques on soil moisture storage, growth and yield of dryland grain sorghum:

(1) Flatbed (standard conventional tillage; control; treatment 1)
(2) Deep planting basins/potholes (treatment 2)
(3) Open end tied ridges, planting on ridges (treatment 3)
(4) Open end tied ridges, planting in furrows (treatment 4)
(5) Closed end tied ridges, planting on ridges (treatment 5)
(6) Closed end tied ridges, planting in furrows (treatment 6)

3.4. Soil moisture measurements
The soil water content (volumetric) was measured to a depth of 0.12 m with a Hydro Sense Water Tester (Campbell Scientific, Logan, UT, USA). The water tester uses time domain reflectometry. It consists of a sensor with two 0.12 m probe rods connected to a display/control unit. Thirty measurements were conducted in each treatment (10 in each replicate) by fully inserting the probe rods into the soil and taking reading from the display unit at 7-day intervals from 7 to 126 DAP. Soil water measurements were conducted in the deep basin for deep basin tillage plots, on the ridges and in the furrows for open and closed end tied ridges plots.

3.5. Biometric measurements

3.5.1. Plant height and stem diameter
Plant height and stem girth are important crop growth parameters that have a considerable influence on grain yield of dryland sorghum. The sorghum plant height was measured using a 2.5 m ruler from the soil surface to the tip of the sorghum plant. The stem diameter was measured above the first node of the sorghum plant from the soil surface, using a vainer caliper. Ten randomly selected plants of the four central plant rows of each plot were chosen for the plant height and stem diameter measurements. The plant height and stalk girth were measured at 14; 28; 42; 56; 70; 84; 98; 112; and 126 days after transplanting (DAP) for the 2016/17 and 2017/18 farming seasons.

3.5.2. Leaf area index (LAI)
The leaf area index, which is the ratio of total one-sided area of photosynthetic tissue to ground surface area, was measured at 14; 28; 42; 56; 70; 84; 98; 112; and 126 DAP. The LAI was measured using an LAI-2000 plant canopy analyzer (LI-COR, Lincoln, Nebraska, USA) on 10 randomly selected plants of the four central plant rows of each plot. Measurements were taken when the sun was near the horizon, that is, within two hours after sunrise or before sunset, to get the low angle diffused radiation as per the manufacturer's specifications. Leaf area index was calculated from the ratio of below-canopy to reference measurements using the software provided by the manufacturer. Data were screened to eliminate below-canopy readings which exceeded reference above-canopy readings of irradiance.

3.5.3. Root measurements
Trenches running along and across plants rows were dug for a randomly selected row in each replicate plot. Two trenches along rows ran 15 cm on either side of the plant row with target plant station. The trenches were 25 cm wide;180 cm long and 150 cm deep. The roots were washed using water under moderate pressure starting from either side of the row with target plant station *insitu*. Three plant stations were washed with the target plant in the middle for every sampling event in the plot. The soil accumulating in the trenches was removed using shovels. After removing

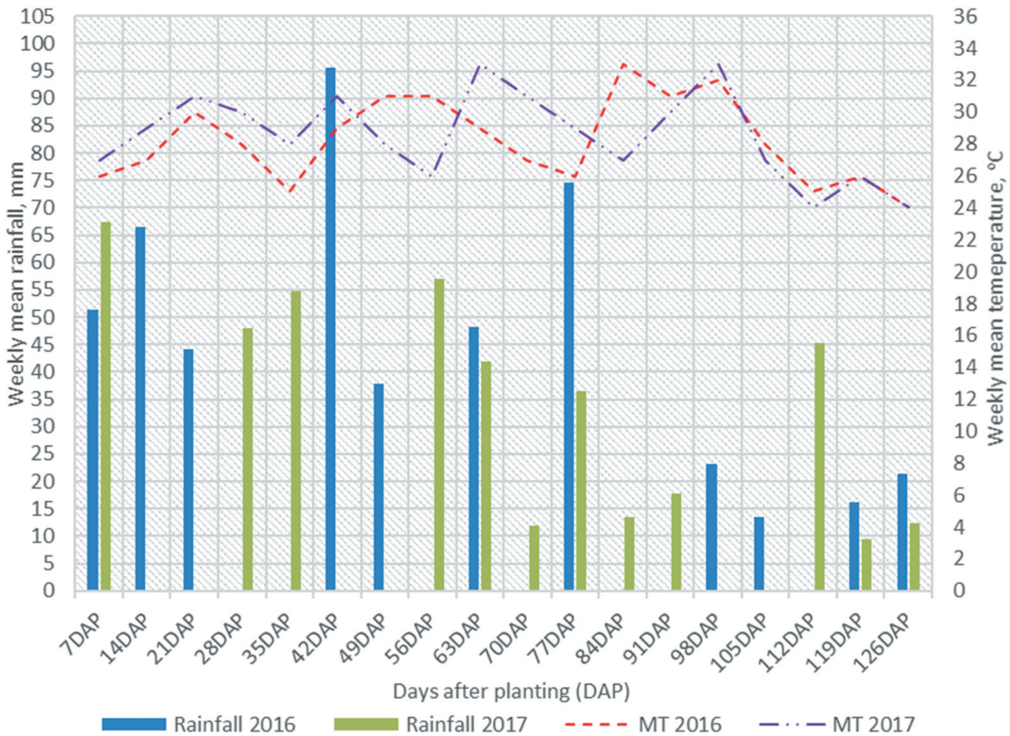


Figure 2. Weather conditions during the 2016 and 2017 summer seasons. DAP—Days after planting.

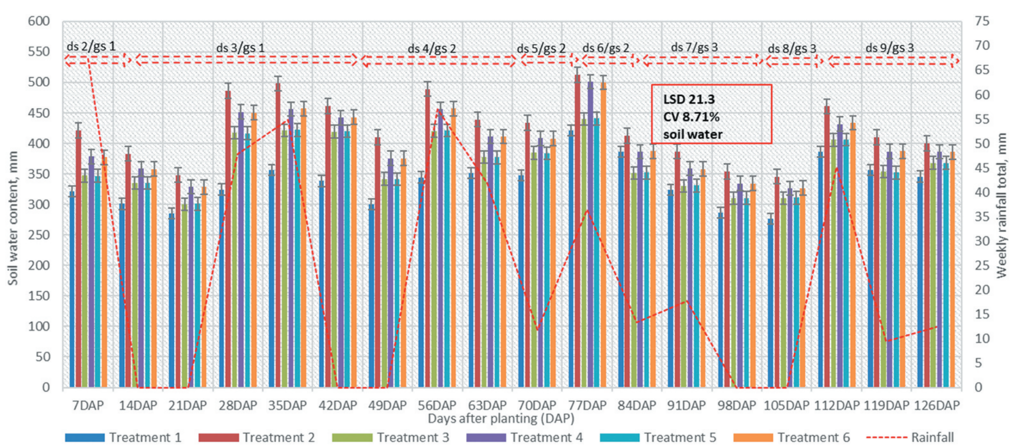


Figure 3. Soil water content in conservation tillage treatments over study period (2016). DAP—days after planting; ds—development stage; gs—growth stage.

the target plant, the soil was shoveled back to close the trenches. The excavated target plants were suspended on a tripod. The adventitious root thickness and length were measured using caliper and ruler, respectively. Mean root thickness and length were computed and recorded for each replicate plot. The root measurements were conducted at 14; 28; and 42 DAP.

3.5.4. Grain yield and yield components

Sorghum panicles were harvested at physiological maturity in order to determine the panicle length and grain yield by harvesting a statistically representative area of two rows of 5.0 m long from the middle of each treatment. The panicles were harvested manually and threshed using

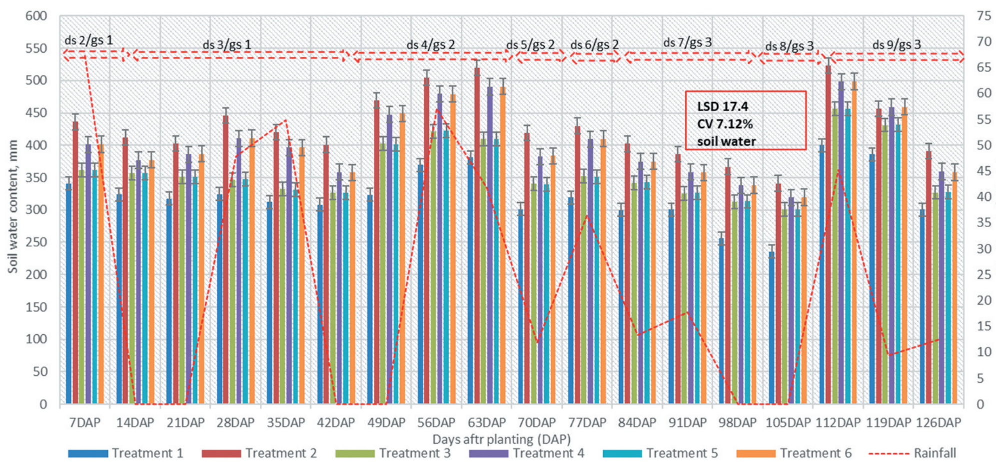


Figure 4. Soil water content in conservation tillage treatments over study period (2017). DAP—days after planting; ds—development stage; gs—growth stage.

a threshing machine after sun drying them to 13% grain moisture level. Then, the panicles were carefully detached from the stalk and used for measuring panicle length and yield components. Panicle length was measured as the length between the base and tip of a panicle. The grain yield from the sample area was computed kg ha^{-1} at 13% grain moisture for all the treatments. The grain sampled from each plot was weighed to the nearest tenth of a kg. Randomly selected 1000 kernel from the plots were weighed and recorded. The sampling area grain yield was computed to grain yield per hectare.

3.5.5. *Statistical analysis*

The treatment effects on measured variables were analyzed using GLM procedure of SAS Statistical Software Version 9.1 (Statistical Analysis System (SAS) Institute, 2002). Differences between treatment means were judged significant at $p \leq 0.05$ as determined by Fisher's protected least significant difference test. Mean separation was performed using the LSD. Statistical significance of the differences between measured variables in the plots which were subjected to tillage types was established by performing t-test for unpaired samples.

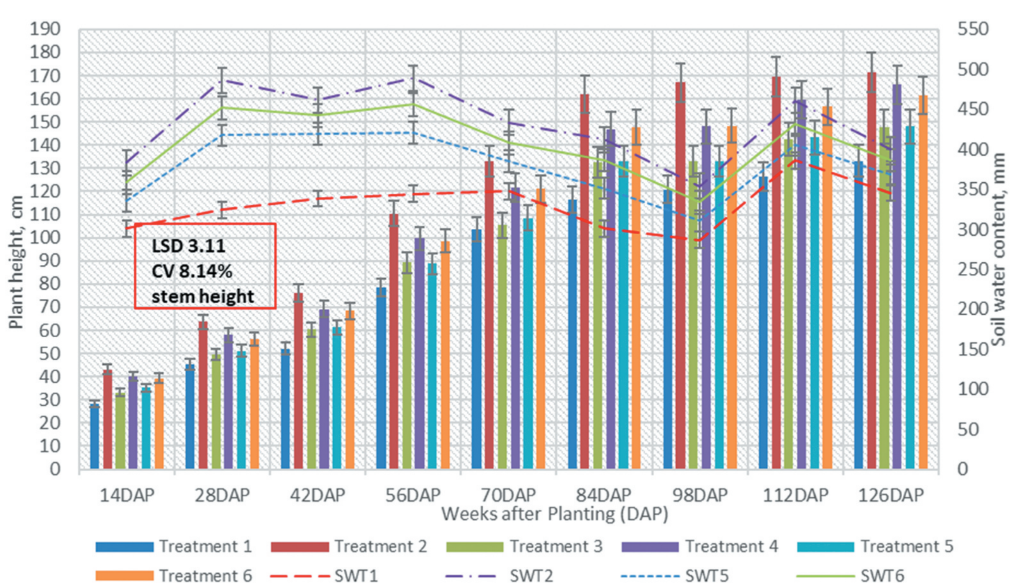


Figure 5. The effect of conservation tillage on sorghum stem height (2016). DAP—days after planting; SW—soil water; T—treatment.

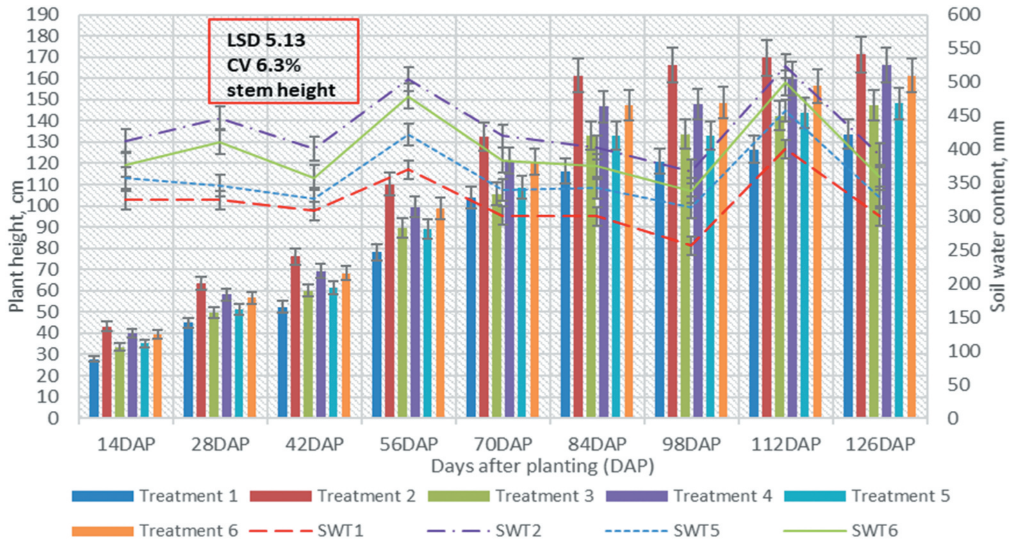


Figure 6. The effect of conservation tillage on sorghum stem height (2017). DAP—days after planting; SW—soil water; T—treatment.

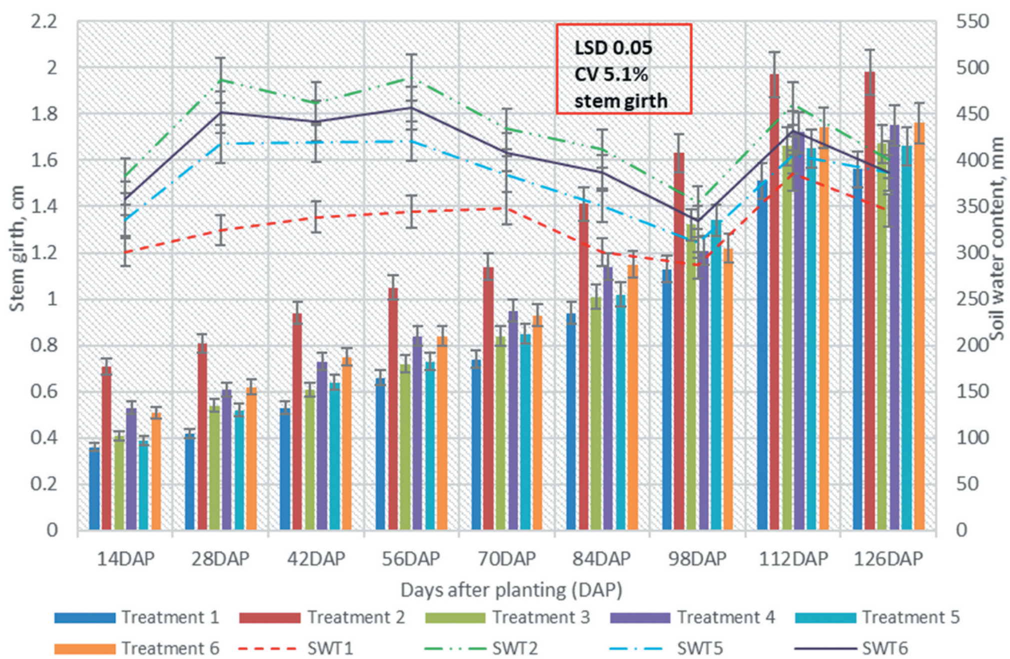


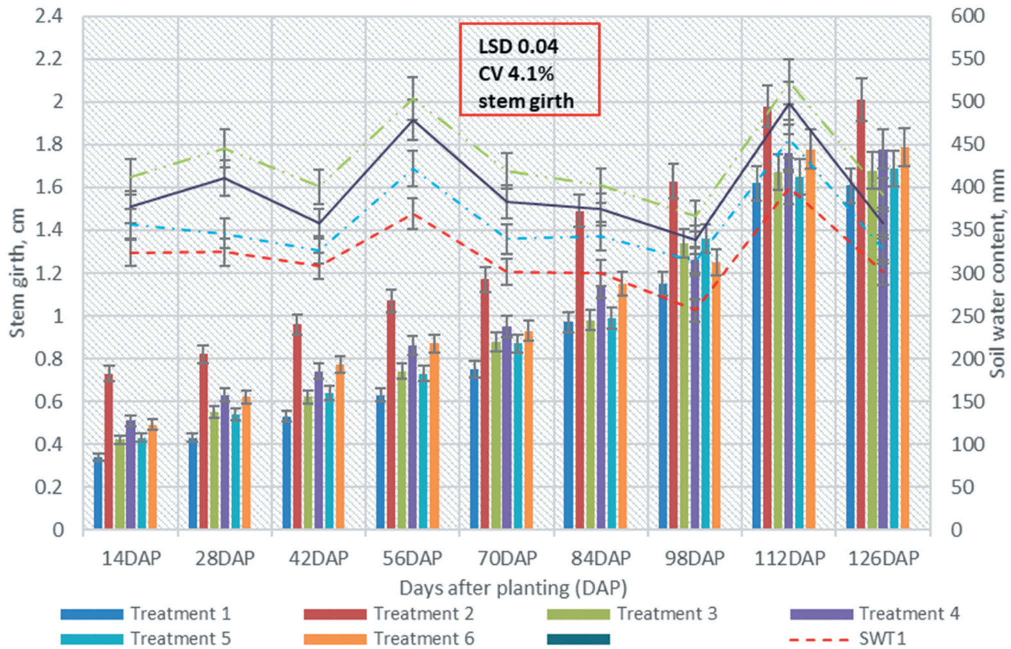
Figure 7. Influence of conservation tillage on sorghum stem girth (2016). DAP—days after planting; DAP—days after planting; SW—soil water; T—treatment.

4. Results

4.1. Description of weather and soil moisture conditions

The Save Valley Experiment Station is located in a semi-arid environment with a long-term average annual rainfall of 590 mm. The experimental site received annual rainfall totals of 492.0 and 508 mm during the 2016/17 and 2017/18 farming seasons, respectively. The rainfall distribution for the two farming seasons were highly erratic with frequent mid-season droughts (Figure 2). The total annual rainfall recorded during the 2016/17 and 2017/18 farming seasons were 98 mm (16.6%) and 82 mm (13.9%) below the long-term average of 590 mm.

Figure 8. Influence of conservation tillage on sorghum stem girth (2017). DAP—days after planting.



The mean air temperature readings were 28.2 and 28.6°C for the years 2016/17 and 2017/18 farming seasons, respectively (Figure 2). The area experiences a greater diurnal range in temperature that is warmer in summer and cooler in winter without frost periods.

Figures 3 and 4 show the dynamics of soil water content in plots subjected to conventional and in-field rain water harvesting (conservation) tillage types over the study period. When compared with the control (flatbed tillage), conservation tillage methods significantly ($p \le 0.05$) elevated the content of soil water over the 2016/17 and 2017/18 farming seasons. However, mean separations between the content of soil water on the ridges of open end tied ridges (treatment 3) and ridges of closed end tied ridges (treatment 5) were not significant ($p \ge 0.05$) over the 2016/17 and 2017/18 study periods. Similarly, soil moisture accumulations in the furrows of open end tied ridge plots were not significantly different ($p \ge 0.05$) from those observed in the furrows of the closed end tied ridge plots for the two farming seasons

Among the conservation tillage plots, ridges and furrows of open and closed end tied ridge plots accumulated significantly lower ($p \le 0.05$) soil water content than that observed in deep basins (Figures 3 and 4). Results indicate that, on average, deep basin conservation tillage increased mean soil water content by 13.3% (56.5 mm) and 6.2% (26.4 mm) above the mean soil water content recorded on ridges and in furrows of plots subjected to open and closed end tied ridging for the 2016/17 summer season, respectively. In the 2017/18 farming season, mean soil moisture content in deep basin tillage plots were 15.9% (68.4 mm) and 6.2% (26.6 mm) in excess of the soil moisture accumulations recorded on ridges and furrows of the open and closed tied ridge plots, respectively.

The substitution of conventional tillage method with deep basin; open and closed tied ridges with sorghum planting on the ridges and furrows elevated water content in soil by 88.8 mm (26.4%); 32.9 mm (9.7%) and 62.6 mm (18.6%), respectively, over the 2016/17 farming season. In the 2017/18 cropping season, soil water accumulation in deep basins; open- and close-ended tied ridges with planting on ridges and in furrows exceeded that recorded in conventional tillage plots by 107.0 mm (33.2%); 38.6 mm (12.0%) and 80.4 mm (24.9%), respectively.

Results presented in Figures 3 and 4 indicate that accumulations of soil water were 30.1 mm (8.2%) and 41.8 mm (11.6%) higher in the furrows of the open (treatment 4) and closed (treatment 6) tied ridges than those recorded on the crests of the open (treatment 3) and closed (treatment 5) end tied ridges tillage plots for the 2016/17 and 2017/18 growing seasons, respectively.

4.2. Effect of conventional and conservation tillage on sorghum stem height and girth

Culm length and girth measurements were performed at 14-day intervals up the 126 DAP (Figures 5–8). Significant differences ($p \leq 0.05$) in the means of sorghum stalk length and girth were found among plants growing in conventional and conservation tillage plots over two seasons of field trials. The measured variabilities in soil water content superimposed on the sorghum stalk length and girth results in Figure 5 to 8 displayed comparatively substantial effects ($p \leq 0.05$) of soil moisture dynamics on sorghum stem length and girth.

However, mean separations between the plant height and girth of sorghum plants growing on the ridges and in furrows of open (treatment 3) and closed (treatment 5) ridge plots were not significant ($p \geq 0.05$) over the 2016/17 and 2017/18 farming seasons.

Plant height increased linearly and significantly ($p \leq 0.05$) with the increase in the accumulation of soil water during vegetative growth of the crop in 2016/17 and 2017/18 summer seasons (Figure 5 to 8). Results have shown that the highest plant heights were recorded in plants growing in deep basin tillage plots (Figures 5 and 6). Planting the sorghum transplants in deep basins substantially increased stem lengths by 22.5 cm (22.5%) and 11.0 cm (9.9%) when compared with stem lengths recorded in plants growing in on the ridge and furrow of open and closed end tied ridges treatments (Figures 5 and 6) for both seasons, respectively. The substitution of conventional flatbed sorghum planting with sorghum planting in deep basins; on ridges and in furrows of open and closed tied ridges can significantly increase sorghum plant heights, on average, by 32.4 cm (36.2%); 9.9 cm (10.0%) and 21.4 cm (19.3%), respectively, for both seasons.

Mean stem girths of sorghum transplants growing in deep basins over the 2016/17 summer season substantially exceeded stem girths of plants on ridges (treatments 3 and 5) and furrows (treatments 4 and 6) of open and closed tied ridge plots by 0.31 mm (31.6%) and 0.23 mm (21.7%), respectively. Stem diameters of sorghum plants growing in deep basins, ridges and

Figure 9. Root length responses to conventional and conservation tillage (2016). DAP—days after planting; SW—soil water; T—treatment.

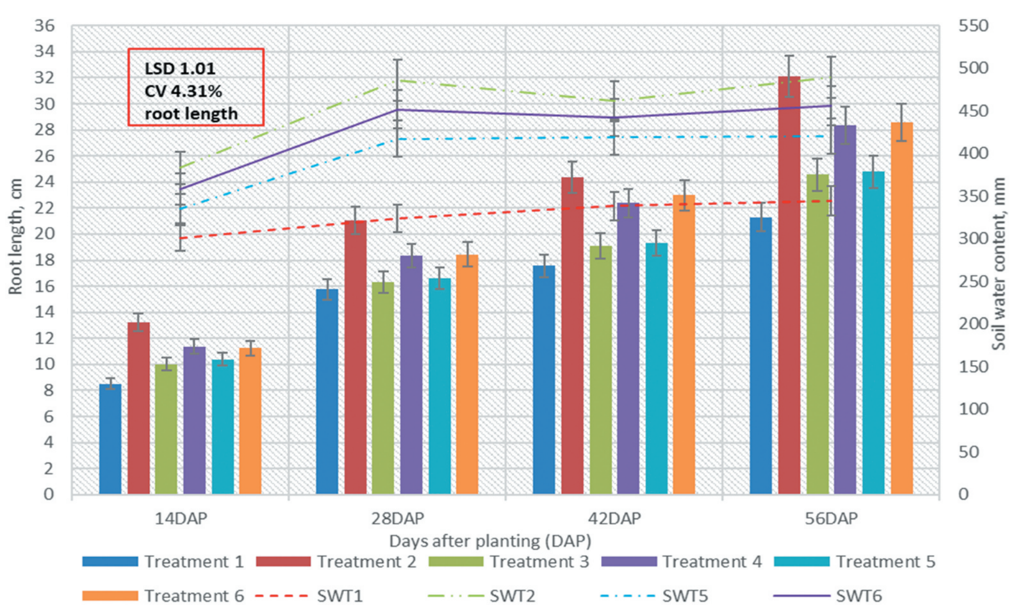


Figure 10. Root length responses to conventional and conservation tillage (2017). DAP—days after planting; SW—soil water; T—treatment.

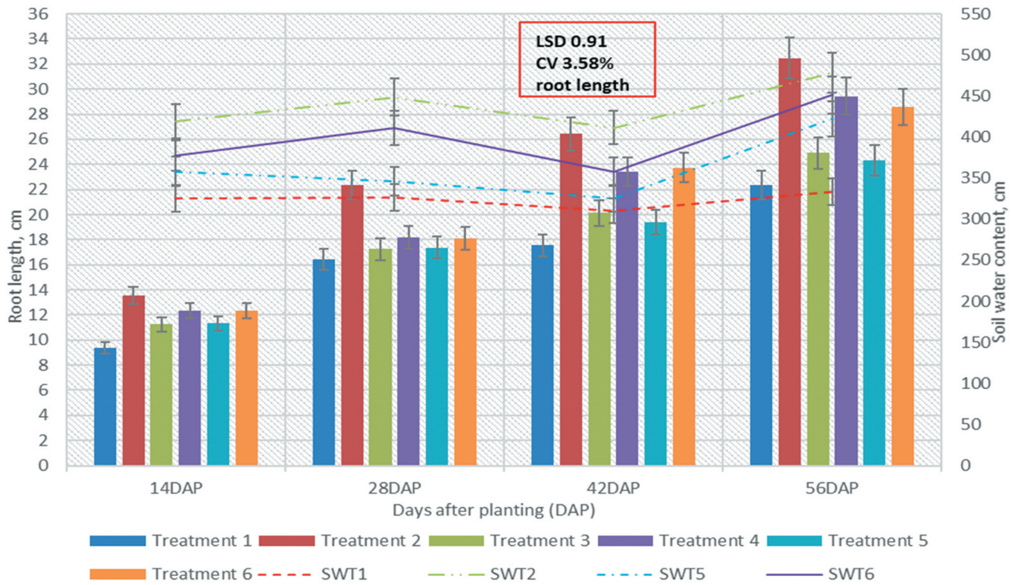
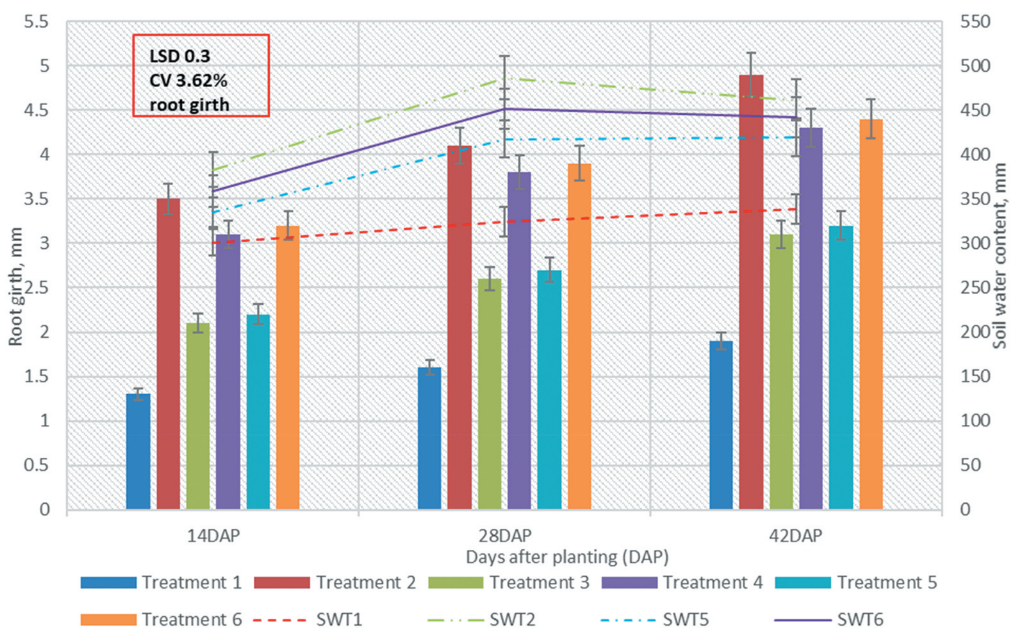


Figure 11. Root girth responses to conventional and conservation tillage (2016). DAP—days after planting; SW—soil water; T—treatment.



furrows of open and closed end tied ridges were 0.42 mm (48.3%); 0.11 mm (12.6%) and 0.19 mm (21.8%) thicker than those recorded in transplants planted on the flatbed (control plots, treatment 1) during the 2016/17 growing season.

The stems of the sorghum transplants growing in deep basin tillage plots scored 0.32 mm (32.0%) and 0.25 mm (23.4%) thicker stems than those recorded in plants propagated on the ridges and in furrows of the open- and close-end tied ridges plots over the 2017 summer season (Figures 7 and 8).

Figure 12. Root girth responses to conventional and conservation tillage (2017). DAP—days after planting; SW—soil water; T—treatment.

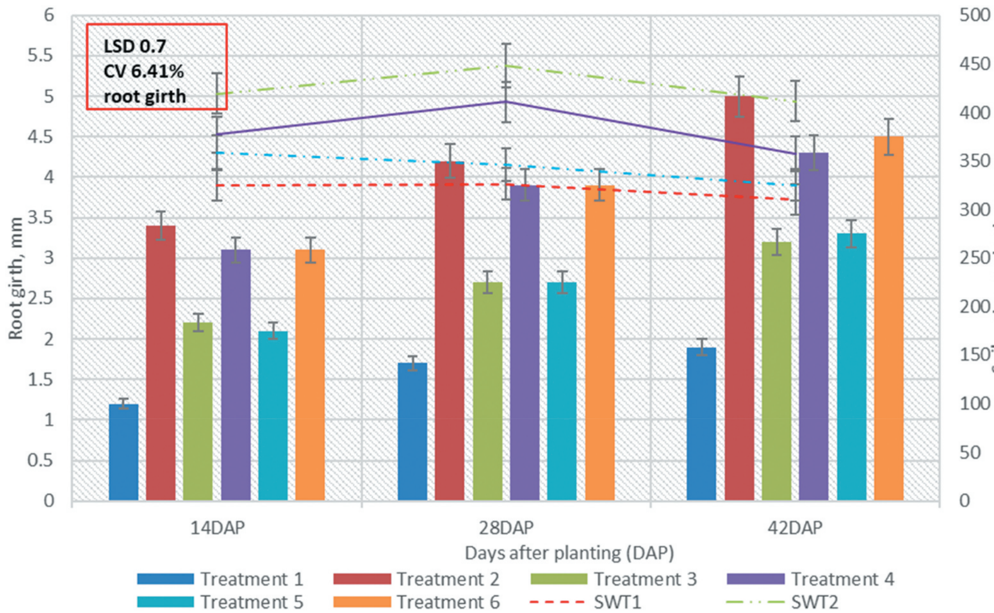
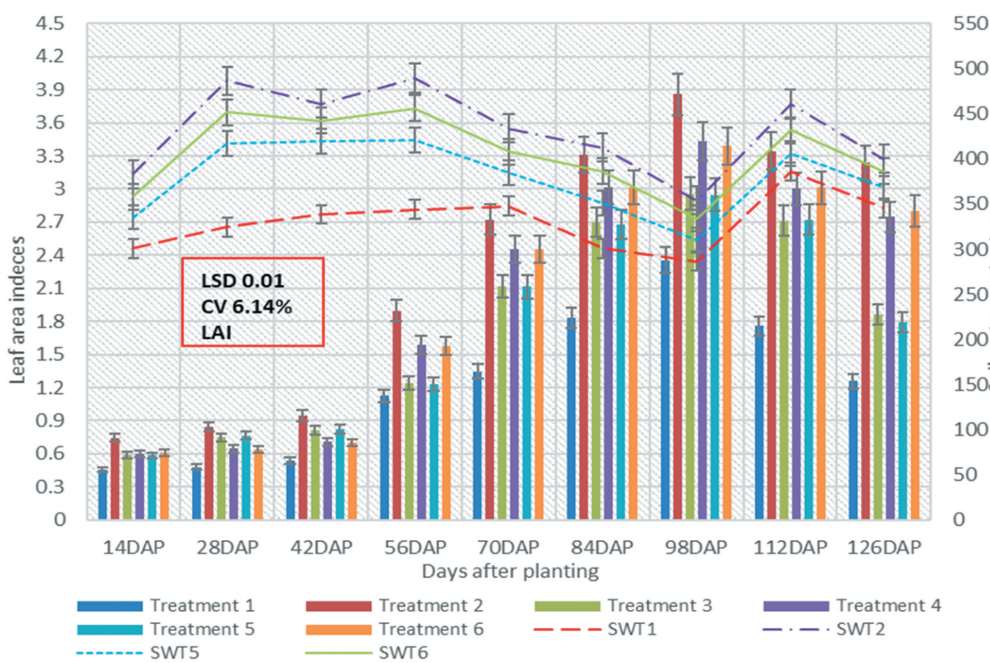
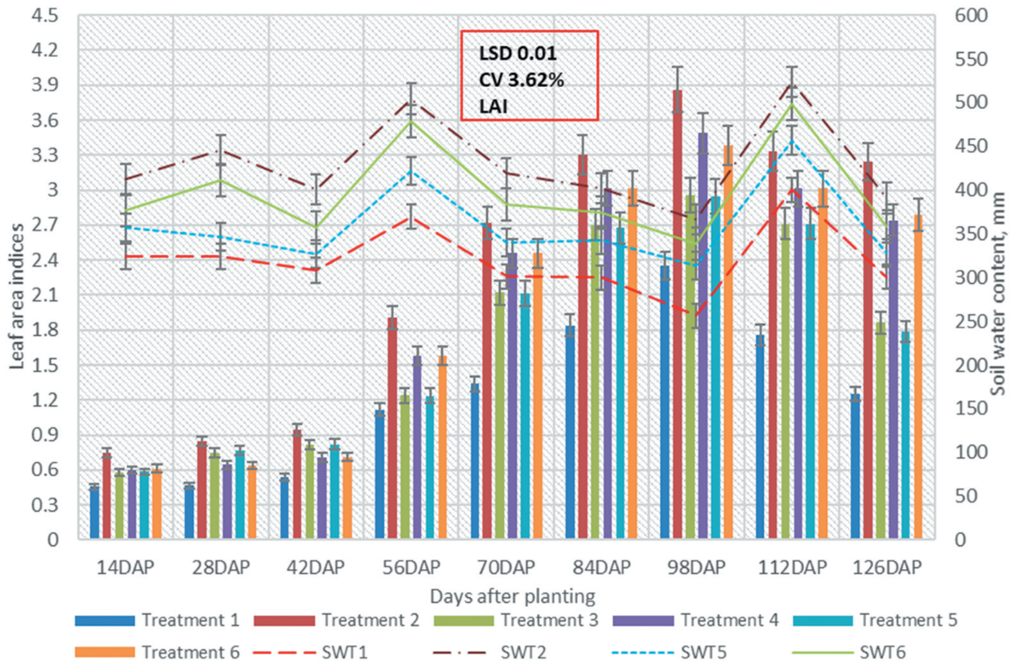


Figure 13. Leaf area index responses to conventional and conservation tillage (2016). DAP—days after planting; SW—soil water; T—treatment.



The substitution of sorghum plant propagation in the furrows of the open (treatment 4) and closed (treatment 6) tied ridges by sorghum plant propagation on ridges of the open (treatment 3) and closed (treatment 5) end tied ridges for the 2016/17 and 2017/18 growing seasons escalated plant height, on average, by 11.5 cm (11.6%). Mean stem diameters of plants growing in the furrows of the open- and close-end tied ridges plots over the 2016/17 and 2017/18 growing seasons were 0.08 mm (8.2%) and 0.07 mm (7.0%) in excess of those recorded in sorghum plants propagated on the ridges of the open- and close-end tied ridges plots, respectively.

Figure 14. Leaf area index responses to conventional and conservation tillage (2017). DAP—days after planting; SW—soil water; T—treatment.



Temporal variabilities in sorghum lengths and girths appeared clearly to increase as the season progressed.

4.3. Effect of conventional and conservation tillage on sorghum root length and girth

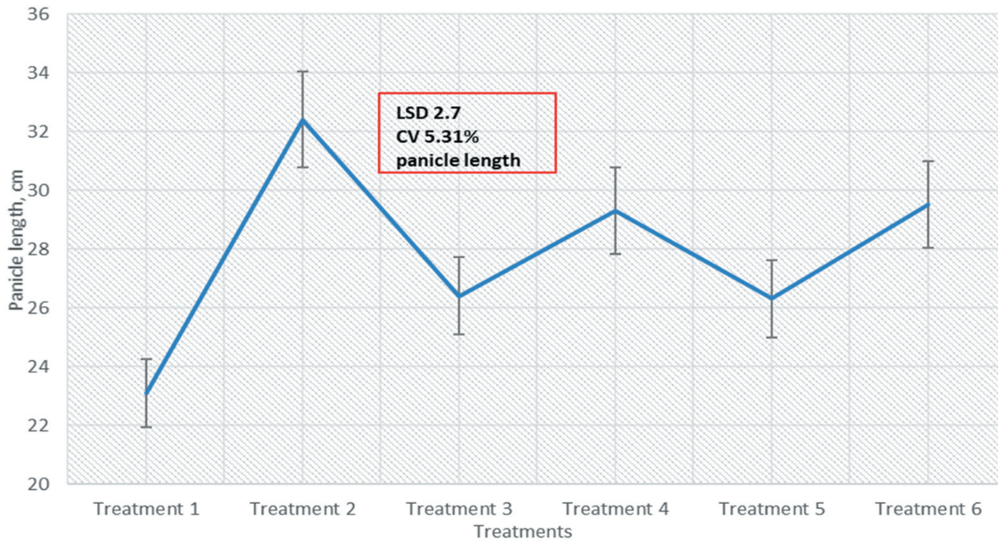
The superimposition of the measured variabilities in soil water content on the sorghum root length and girth findings in Figure 9 to 12 exposed a considerably substantial effect of soil moisture dynamics on sorghum root length and girth. Results over the two growing seasons have shown comparatively significant ($p \leq 0.05$) influence of the conventional and conservation tillage methods on sorghum root length and girth over the vegetative growth period of sorghum (Figures 9–12). Root lengths in the deep basins, open- and close-end tied ridges with ridge planting (treatments 3 and 5) and open- and close-end tied ridges with plants in furrows exceeded the root lengths of sorghum plants in conventional tillage plots (control, treatment 1) by 6.91 cm (43.8%); 1.72 cm (10.9%) and 4.53 cm (28.7%) in 2016/17, respectively.

Root length measurement results in the 2016/17 study period indicate that mean root lengths of the plants grown in deep basins (treatment 2) clearly out performed those recorded in the open- (treatment 3 and 5) and close (treatment 4 and 6)-end tied ridges by 5.19 cm (29.7%) and 2.38 cm (11.7%), respectively (Figure 9). Similarly, roots of sorghum plants in deep basin tillage plots were 5.33 cm (29.0%) and 3.0 cm (14.5%) longer than those observed in sorghum plants of the open- and close-end tied ridges in 2017/18, respectively (Figure 10).

Sorghum plant roots grown in furrows (treatments 4 and 6) were 2.81 cm (16.1%) and 2.33 cm (12.7%) longer when compared with root lengths recorded in plants grown on ridges of the open- and close-end tied ridges (treatments 3 and 5) in the 2016/17 and 2017/18 farming seasons, respectively.

When compared with the control, root diameters of plants in basin tillage, on ridges and in furrows of open- and close-end ridge plots were 2.6 mm (162.5%); 1.0 mm (62.5%) and 2.2 mm (137.5%) wider, respectively, for both years (Figures 11 and 12). Roots of sorghum plants growing in the furrows of open- and close-end tied ridges were 1.2 mm (46.2%) thicker than those recorded

Figure 15. Panicle length response to conventional and conservation tillage (2016).



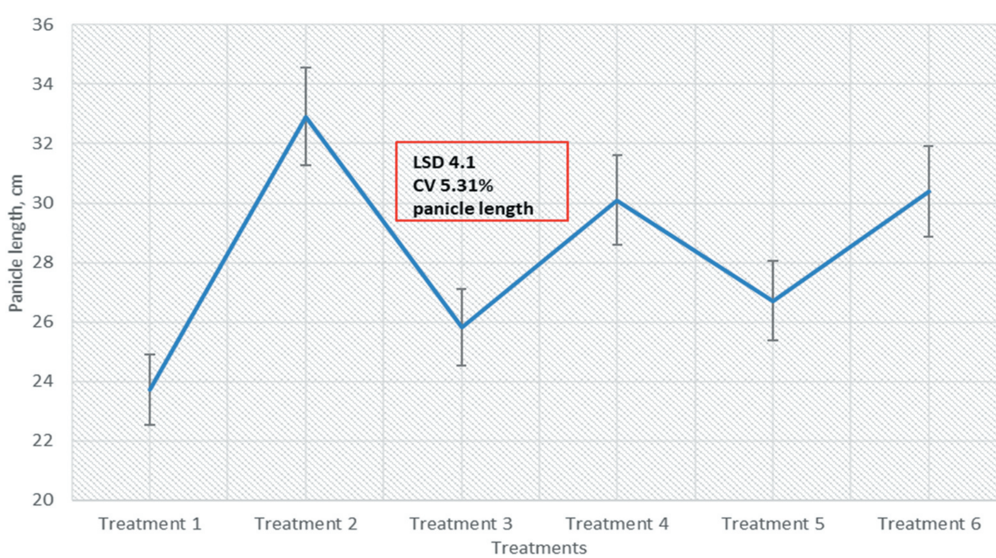
in sorghum plants growing on ridges of the open- and close-end tied ridges plots (Figures 11 and 12).

Mean separations between the root length and girth of the sorghum crop growing on the ridges and in furrows of open (treatment 3) tied ridge plots and the root length and girth of plants growing on ridges of the closed end tied ridge plots were not detectable ($p \geq 0.05$) over the 2016/17 and 2017/18 farming seasons.

4.4. Leaf area index response to conventional and in-field rain water harvesting techniques

Conventional and in-field rain water harvesting tillage methods exerted a considerable influence on the variabilities in soil water content (Figures 3 and 4) and, as a consequent, the tillage methods significantly ($p \leq 0.05$) influenced changes in leaf are indices (LAI) (Figures 13 and 14). The highest LAI values were recorded in deep basin tillage and the lowest values were found in conventional

Figure 16. Panicle length response to conventional and conservation tillage (2017).



tillage plots. Nevertheless, mean separations between the sorghum LAI in plots subjected to open (treatment 3) and closed (treatment 5) end tied ridges with planting on the ridges were not significant ($p \geq 0.05$) over the 2016/17 and 2017/18 farming seasons. Correspondingly, variations in the LAI in open (treatment 4) and closed (treatment 6) end tied ridges plots where sorghum transplants were planted in furrows were not discernible ($p \geq 0.05$) over the two season study. Leaf area indices progressively increased with increasing period up to 98 DAP. Thereafter, the LAI values declined considerably until 126 dap. Mean LAIs increased from 2.3544 at 14 DAP to a peak of 3.3798 at 98 DAP before steadily declining to 2.7863 at 126 DAP (Figure 13).

Generally, mean LAI responses to conventional and in-field rain water harvesting tillage methods and ultimately to accumulations of soil moisture in 2016/17 were consistently similar to those in recorded in 2017/18 (Figures 13 and 14). Mean LAI values in plots subjected to deep basin (treatment 2), open- and close-end tied ridges with planting on ridges (treatments 3 and 5) and furrows (treatments 4 and 6) were 1.0844 (87.6%); 0.5093 (41.1%) and 0.7836 (63.3%) larger than the mean LAI values in the conventional tillage plots for both seasons (Figures 13 and 14). The superior soil moisture conservation potential in the deep basin tillage variants were translated to the highest LAI values being recorded in the basin tillage plots. When compared with mean LAI values in the open- and close-end tied ridges with planting on the ridges and in furrows, basin tillage mean LAI values of the sorghum plants were larger by 0.5751 (32.9%) and 0.3008 (14.9%), respectively.

4.5. Dryland grain sorghum yield and panicle length responses to tillage methods

Dryland sorghum production in sub-tropical Africa is characterized by considerable variability in yield as crop performance depends highly on soil moisture availability. Figures 15 and 16 show the dynamics of sorghum panicle lengths at harvesting under conventional and conservation tillage methods. The conservation of higher moisture in soil profile in conservation tillage compared to conventional tillage produced considerably longer ($p \leq 0.05$) sorghum panicles. Overall results of the current study showed that sorghum plants in the deep basin tillage plots exhibited, significantly, the longest panicle lengths ($p \leq 0.05$) in 2016/17 and 2017/18 study periods.

Mean panicle lengths of the 2016/17 sorghum crop grown in the deep basins exceeded the panicle lengths of the sorghum crop in plots subjected to open and closed end tied ridges with

Figure 17. Tillage method effect on weight of 1000 grains and yield of sorghum (2016). GW—grain weight; YLD—yield.

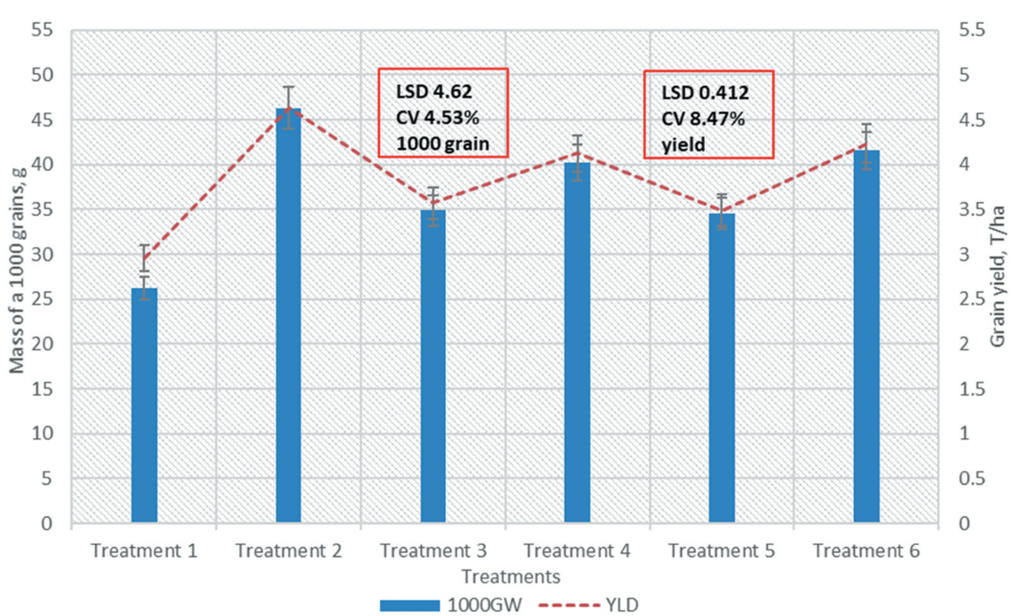
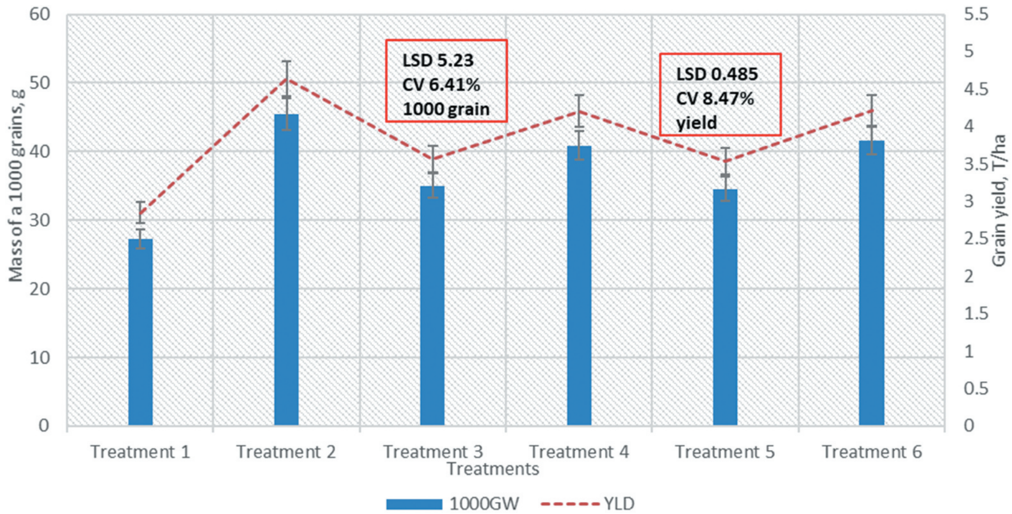


Figure 18. Tillage method effect on weight of 1000 grains and yield of sorghum (2017).



plants growing on the ridges (treatments 3 and 5) and in the furrows (treatments 4 and 6) by 6.0 cm (22.7%) and 2.9 cm (9.8%), respectively. In the same year, panicle lengths of the sorghum crop in deep basins, open- and close-end tied ridges with plants on the ridges and furrows were 9.3 cm (40.3%); 3.3 cm (14.3%) and 6.4 cm (27.7%) longer than those observed in the conventional tillage plots, respectively. The sorghum crop grown in furrows of the open- and close-end tied ridges carried panicles which were 3.1 cm (11.7%) longer than the panicles exhibited by plants grown on the ridges of open and closed end tied ridges.

In 2017/18 farming season, the sorghum crop grown in deep basin rain water harvesters exhibited panicles which were 7.1 cm (27.5%) and 2.5 cm (8.2%) longer than those observed in the crop grown on the ridges and furrows of the open- and close-end tied ridges plots (Figure 16). Panicle lengths of the crop in conventional tillage plots (flatbeds, control) were 9.2 cm (38.8%); 2.1 cm (8.9%) and 6.4 cm (27.7%) shorter than the panicles carried by the crop planted in deep basins; open- and close-end tied ridges with the crop on the crest and furrows, respectively (Figure 16).

The analysis of variance for the 2016/17 and 2017/18 results showed that the main effects of both tillage methods and soil moisture storage on thousand kernel weight and grain yield of dryland sorghum were significant ($p \le 0.05$). These important biometric parameters distinctly improved with every increment in in-field rain water harvesting potentials and, ultimately, soil moisture storage levels (Figures 17 and 18).

The highest 1000 kernel weights of 46.3 g and 45.47 g were observed in the deep basin tillage plots (Figures 17 and 18). Increased soil water content in plots subjected to deep basin (treatment 2); open and closed end tied ridges covered with sorghum plants on the ridges (treatments 3 and 5) and in the furrows (treatments 4 and 6) improved the weights of a 1000 kernels in these plots by 20.07 g (76.5%); 8.64 g (32.9%) and 15.36 g (58.5%) in excess of the 1000 grain weights recorded in the control plots (treatment 1) in 2016/17 summer season, respectively. In the same year, land preparation methods involving deep basin in-field water harvesting techniques could improve a 1000 kernel weight of sorghum by 11.43 g (32.8%) and 4.72 g (11.4%) above those observed in open and closed end tied ridges plots planted on the ridge (treatments 3 and 5) and in the furrows (Treatments 4 and 6), respectively. A thousand grain weight of the sorghum crop grown in the furrows (treatments 4 and 6) were 6.71 g (19.2%) heavier than the weights of a similar number of grains recorded in plants grown on the ridges of open- and close-end tied ridges in 2016/17 farming season.

When compared with the control, 1000 kernel weight of sorghum grain harvests in deep basin (treatment 2), open- (treatment 3) and close (treatment 5)-end tied ridges tillage with planting on the ridges and in furrows (treatments 4 and 6) tillage plots were 18.21 g (66.8%); 7.75 g (28.4%) and 14.35 g (52.6%) heavier, respectively. The use of the deep basin in-field rainwater harvesting method (treatment 2) can significantly increase thousand grain weight by 10.46 g (29.9%) and 3.86 (9.3%) above those observed in the open (treatment 3) and closed (treatment 5) end tied ridges planted on the ridges and in the furrows (treatments 4 and 6), respectively (Figure 18).

The results showed that the dryland sorghum grain yield was significantly ($p \leq 0.05$) influenced by the in-field rain water harvesting methods in 2016/17 (Figure 17) and 2017/18 (Figure 18). The highest grain yield was observed in the deep basin tillage (4.635 T ha^{-1}) followed by that in the open (treatment 4) and closed (treatment 6) end tied ridges with planting in the furrows (4.235 T ha^{-1} in 2016 and 4.209 T ha^{-1} in 2017). Grain yield dried to 12.5% moisture level in deep basins (treatment 2), open (treatment 3) and closed (treatment 5) end tied ridges planted on the ridges and furrows (treatment 4 and 6) supported grain yield of 1.679 T ha^{-1} (56.8%); 0.612 T ha^{-1} (20.7%) and 1.279 T ha^{-1} (43.3%) higher than the harvests in the control plots (Figure 17).

In 2016/17, grain yield obtained from the deep basin tillage plots (treatment 2) was 1.067 T ha^{-1} (29.9%) and 0.400 T ha^{-1} (9.4%) above that harvested from plots that were subjected to open (treatment 3) and closed (treatment 5) end tied ridges planted on the ridges and furrows (treatments 4 and 6), respectively (Figure 17). Grain yield in deep basin; open- and close-end tied ridges with the sorghum crop grown on the ridges and in furrows was 1.786 T ha^{-1} (62.7%); 0.719 T ha^{-1} (25.2) and 1.360 T ha^{-1} (47.7%) higher than that received from the control plots in 2017 (Figure 18). When the sorghum crop was propagated in deep basins (treatment 2), the grain yield considerably increased by 1.067 T ha^{-1} (29.9%) and 0.426 T ha^{-1} (10.1%) in excess of that harvested from open (treatment 3) and closed (treatment 5) with planting on the ridges and in the furrows (treatments 4 and 6), respectively.

The grain yield of sorghum grown in furrows was 0.667 (18.7%) and 0.641 (18.0%) higher than the grain yield harvested from the crop grown on the ridges of the open (treatment 3) and closed (treatment 5) end tied ridges plots, respectively, for the farming seasons 2016/17 and 2017/18 (Figures 17 and 18).

5. Discussion

5.1. Effect of in-field water harvesting tillage methods on soil water dynamics

Yield gap analysis in various studies conducted in the water-scarce semi-arid regions of Zimbabwe consistently reported rain-fed grain sorghum yields that are lower than the regional average of 800 kg ha^{-1} due to water-related constraints (Mupangwa et al., 2012; Rockstrom et al., 2009; Twomlow et al., 2006). The growing season of the dryland sorghum crop in the dry area of Zimbabwe is generally characterized by frequent intra-seasonal dry spells, which severely limit crop productivity if the drought spells coincide with critical stages of crop development (Baudron et al., 2011; Rockstrom, 2003a; Wani et al., 2003). In a study on the spatio-temporal trend analysis of rainfall and temperature extremes in the Vea Catchment in Ghana, larbi et al. (2018) reported a considerable influence of rainfall distribution and temperatures extremes on growth and development of sorghum.

The 2016/17 and 2017/18 farming seasons recorded yearly totals of 492.0 and 508 mm, respectively, which were below the long-term annual average of 590 mm. In a study on measured and simulated evapotranspiration of grain sorghum Tolk and Howell (2001) reported a requirement of 550 mm of water during the growing season of medium to late maturing sorghum cultivar (maturity within 110 to 130 days). The deficit in annual precipitation recorded in both seasons is usually associated with lower sorghum crop productivity on the account of limitations imposed by soil water depletions. Trends in the selected growth parameters over the two farming seasons show that the severity of the negative impacts of the mid-season dry spells was more profoundly exhibited by the sorghum crop grown in plots subjected to flatbed conventional tillage plots. In contrast, the sorghum crop grown under in-field rain water harvesting tillage methods displayed considerably lower susceptibilities to intra-seasonal drought-induced moisture stress due to the improved rain water harvesting and storage potential in conservation tillage plots.

In the current study, the 2016/17 and 2017/18 farming seasons recorded at least three major mid-season droughts. There were generally declining rainfall trends (Figures 3 and 4) during the last half of the farming seasons coinciding with the critical reproductive stages of the growth and development of the sorghum crop (84–105 DAP for 2016; 70–105 DAP for 2017). A review on grain sorghum water requirement by Assefa et al. (2010) reported considerable influence of the plant-available water on grain sorghum productivity. Among a host of other factors that influence grain sorghum yield, water stress and temperature are of particular importance. Water stress has diverse effects on physiology, growth and development of the sorghum crop, which subsequently determines its final yield depending on the phenological stage at which the water stress occurs. The researchers reported a 36% sorghum yield reduction when water stress occurred during the vegetative stage and more than 55% yield decline with water stress occurring during the reproductive stage. In this respect, the occurrence of intra-seasonal droughts during the reproductive stage (development stage 7/growth stage 3 between 84 and 98 DAP, Figures 3 and 4) was, perhaps, responsible for the lower yield recorded in the conventional tillage plots (Figures 17 and 18).

The greater susceptibility of the sorghum crop in the conventional tillage plots to intra-seasonal dry spells was the account of the subdued rain water harvesting and storage potential of the conventional flatbed tillage seedbed due, in part, to reduced rain water capturing surface roughness. The soil water accumulation over the season was therefore limited in the conventional tillage plots leading limited soil moisture buffer reserve that can be used by the sorghum crop during mid-season dry spells (Kugbe et al., 2019; Lopez-Garrido et al., 2012).

Despite the drop in rainfall during the critical stages in the development of sorghum, soil water conditions remained comparatively moderate for the normal growth of the crop especially in plots subjected to deep basin conservation tillage practices (Figures 3 and 4). In the current study, in-field rain harvesting techniques employed as deep basin, open- and closed-tillage systems substantially increased the content of soil water under the dryland sorghum crop. Increased in-field rain water harvesting and storage potential in deep basin plots substantially elevated soil water accumulations to support yield component development during the severe mid-season dry spells. In a study on soil porosity and water infiltration as influenced by tillage methods, Lipic et al. (2005) reported improved infiltration of rainwater into the soil in artificial rain water harvesting soil surface structures that increase water availability to sorghum plants. In a study on improvement of biomass production Ogbaga et al. (2019) reported increased biomass accumulations with increasing soil water availability.

In the current study it has been established that variabilities in soil water accumulations in furrows and ridges were indifferent to whether the ends of the tied ridges were open or closed. This implies that the use of open end tied ridges imposes similar soil water accumulations as those imposed by the use of closed end tied ridges in furrows and on ridges. This probably is due to the fact that opening the ends of tied ridges has the same rain water harvesting and soil water accumulation potential in furrows and on ridges as those of the tied ridges with closed ends.

5.2. Sorghum vegetative growth response to in-field rain water harvesting methods

All vegetative growth parameters and grain sorghum yield components were significantly affected by the tillage options. Basin tillage practices supported the tallest and thickest sorghum stalks due to their improved in-field rain water harvesting potential coupled with higher water infiltration and storage capacity. In a study on grain sorghum response to row spacing and plant populations in the Texas Coastal Bend region, Fernandez et al. (2012) reported reduced rate of cell expansion and, ultimately, cell size and consequently, growth rate, stem elongation, and leaf expansion under soil moisture stress. The shortest and thinnest stalks observed in the conventional tillage plots were most probably due to the reduced rain water harvesting potential on flat beds and the associated subdued capacity to store soil moisture that can act as buffer soil water reserve for use during mid-season droughts. Rockstrom et al. (2009) reported deceasing sorghum stalk height and leaf appearance under soil water deficit conditions. In a related study on growth of sweet sorghum by Olugbemi et al. (2018), soil moisture content was reported to be strongly correlated to sorghum plant growth rates.

Elevated soil water accumulations in the furrows were followed by longer and thicker stems of the sorghum plants in furrows when compared to stalk length and girth of plants on the ridges of open and closed end tied ridges. Among a host of biotic and abiotic factors, the superior potential of the furrows to harvest rain water and store it in the soil profile of open and closed tied ridges was responsible improved biomass in the form of longer and thicker stems by the sorghum plants in furrows. Benjamin et al. (1990a) simulated the movement of soil water in the ridge and observed that a gradient of water potential caused the water migrate from the ridge to the furrow where it replaced evaporation from the furrow position. For this reason, the soil water content in the furrows appeared to be higher that than that observed on the ridges in the current study. Consequently, considerably greater sorghum crop growth was noted in the furrows when compared with the growth on the ridges of the open and closed tied ridges in the current study.

Sorghum stem length and thickness determine the amount of transitional photosynthate that can be stored in them. At senescence, the photosynthate stored in longer and thicker sorghum culms is usually translocated to the grain for yield formation. In a related study, Gong et al. (2009) reported a 25 to 33% contribution of pre-anthesis assimilate reserves in the stem and leaves of sorghum to the final grain weight.

Results of this research indicate that sorghum plants under conservation tillage alternatives developed considerably longer and thicker fibrous roots when compared with the conventional tillage option. Accessing subsoil moisture implies that sorghum plant roots should be longer to reach deeper into the soil profile in order to allow root access to unconstrained soil water beneath the layers and, therefore, withstand mid-season droughts. Among the conservation tillage variants, sorghum plants in the deep basin tillage plots carried the longest and thickest fibrous roots. The capacity of sorghum plant roots to access available soil water is critical to vegetative growth and development of the crop in water-limited environments. Indeed, the crop's capacity to compete for soil water and nutrients relies on root morphological characteristics, such as root diameter and length (Cantarel et al., 2015; Wang et al., 2005). In a regional comparison of factors affecting global sorghum production study, Mundia et al. (2019) concluded that sorghum plant morphological characteristics are dependent on the soil environmental factors.

After flowering, the sorghum plant expresses development as grain formation (development stage 6 and 7; growth stage 3; Figures 3 and 4). The sugars, amino acids, and proteins generated in the leaves; roots and stems are rapidly translocated to the developing kernel where they are biologically transformed into starch and protein. Consequently, the geometric dimensions of the roots and stems (length and diameter) are fundamental in the determination of the material space for storage of the carbohydrates on transit to the developing grain. The larger the roots and stems of the sorghum crop, the more the storage space for the carbohydrates for translocation to the grain. The adoption of deep basin tillage method ensures that the sorghum plant develops larger roots and stems for transitory storage of carbohydrates that eventually will constitute a higher yield.

The sorghum plant leaf surfaces are the primary border of energy and mass exchange which, ultimately, influence plant biomass accumulations (Bhadha et al., 2016; Wang et al., 2005). Results of the study have demonstrated that the substitution of conventional flat bed with conservation tillage systems considerably elevates the LAI and, consequently, all measured biometric characteristics of the sorghum crop. In this respect, the higher LAI values in deep basin tillage plots was on account of the elevated rain water harvesting potential recorded in in these plots. The LAI values of a crop are an indicator of the capacity of the green matter to intercept visible solar radiation for the formation of photosynthate, which the raw material for building longer and thicker stems, roots and panicles; higher thousand kernel weight and grain yield. A study on plant development and solar radiation interception of four annual forage plants in response to sowing date in a semi-arid environment Zhang et al. (2019) reported increased LAI with improved solar radiation interception by plant leaves.

Results for the two farming seasons indicate that the propagation of sorghum using conventional and conservation tillage methods substantially influenced the variabilities in the thousand grain weight and grain yield of sorghum grown under dryland sub-tropical conditions. Grain sorghum yield in the planting basin tillage plots for both years was correspondingly higher than in the conventional. The thousand grain weight and yield of sorghum were highest in deep basin tillage plots. The measured variables were higher in the open and closed tied ridges with planting on the ridges and furrows when compared with the values obtained in the control plots. The deep basin tillage alternatives displayed comparatively higher rain water harvesting potential and, consequently, an elevated soil water accumulation than the other tillage options (Figures 3 and 4). Reporting on a study on effect of tillage on soil micro-relief, surface depression storage and soil water storage, Guzha (2004) reported greater potential for depression water storage with higher surface roughness. In the current field trial, the improved in-field rainwater harvesting, water infiltration and soil water storage in deep planting basins translated into higher 1000 kernel weight and grain yield.

Related studies on tillage systems and grain yield of sorghum by Hiremath et al. (2003) clearly established that conservation tillage systems can result in substantial gains in soil water due to reduced runoff losses and increased seepage into soil profile. Higher soil moisture retentions in planting basin minimum tillage plots substantially improved the sorghum crop's resilience to the late summer season droughts, which were frequent in the 2016/2017 and 2017/2018 farming seasons (Figures 3 and 4).

6. Conclusions

Accepted wisdom has been that rainfall should be as far as possible be harvested in-field when it falls using tillage methods that effectively reduce surface runoff; increase rain water infiltration and storage. Soil water accumulation acting as buffer reserve during mid-season dry spells can be considerably improved by adopting in-field rain water harvesting tillage methods for increased yield of dryland sorghum production. When compared with conventional; open and closed tied end ridge tillage methods; the deep basin in-field rain water harvesting tillage method significantly improves soil water accumulations. Consequently, the dryland grain sorghum growing in deep basins have significantly longer and thicker stalks and roots; higher values of LAI; longer panicles; heavier thousand grains and higher grain yield. Grain yield obtained from the field trial plots subjected to deep basin; open- and close-end tied ridges with planting in the furrows and on ridges was higher than the average dryland sorghum grain yield of 800 kg ha^{-1} realized by the smallholder farmers in the semi-arid areas of Zimbabwe due the improved rain water harvesting potential.

It has been established in the current study that adopting the conservation tillage systems where tied end ridges are opened introduces homogeneous in-field rain water harvesting and soil water build-ups in furrows and ridges as those observed in tied end ridges with closed ends. As a consequence, plant height, root lengths, and their thicknesses; LAI; panicle length; weight of a thousand kernels and grain yield values of dryland sorghum are not altered by substituting open with closed end tied ridges.

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References

Assefa, Y., Staggenborg, S. A., & Prasad, P. V. V. (2010). Grain sorghum water requirement and responses to drought stress: A review. *Crop Management*, *9*(1), 1–11. https://doi.org/10.1094/CM20101-1109-01-RV

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P., & Giller, K. E. (2011). Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zambia. *Field Crops Research, 132*, 117-128. https://doi.org/101016/j.fcr.2011.09.008

Benjamin, J. G., Blaylock, A. D., Brown, H. J., & Cruse, R. M. (1990a). Ridge tillage effects on simulated water and heat transport. *Soil Tillage Research*, *18*(2–3), 167–180. https://doi.org/10.1016/0167-1987(93)90001-6

Bhadha, J. H., Alvarez, O., Lang, T. A., Giurcanu, M. C., & Daroub, S. H. (2016). Growth efficacy of sorghum and rice amended with dried versus composted aquatic vegetation. *Sustainable Agric Res*, *5*(2), 92–102. https://doi.org/10.5539/sar.v5n2p92

Blake, G. G., & Hartge, K. H. (1986). *Bulk density. methods of soil analysis*. Part 3 ASA Madison.

Botha, J. J., Van Rensburg, L. D., Anderson, J. J., Van Staden, P. P., & Hensley, M. (2012). Improving maize production of in-field rainwater harvesting technique at glen in South Africa by the addition of mulching practices. *Irrigation And Drain*, *61*(Suppl. 2), 50–58. https://doi.org/10.1002/ird.1681

Bouyoucos, G. J. (1965). The clay ratio as a criterion of susceptibility of soils to erosion 1. *Agronomy Journal*, *27* (9), 738–741. Citations: 49. https://doi.org/10.2134/agronj1962.00021962005400050028x. https://doi.org/10.2134/agronj1935.00021962002700090007x.

Bremner, J. M. et al. (1996). N total. In D. L. Sparks, (Eds.), *Methods of soil analysis: Part 3. Chemical methods, (Number 5)* (pp. 1085–1121). Soil Science Society of America. Soil Science Society of America, Inc., American Society of Agronomy, Inc..

Cantarel, A. A. M., Pommier, T., Desclos-Theveniau, M., Diquélou, S., Dumont, M., Grassein, F. (2015). Using plant traits to explain plant-microbe relationships involved in nitrogen acquisition. *Ecology*, *96*(3), 788–799. https://doi.org/10.1890/13-2107.1

Department of Meterological Services. (1981). *Climate handbook of Zimbabwe*.

FAO. (1993) . *Soil tillage in Africa: Needs and challenges*.

FAO/IIASA/ISRIC/ISS-CAS/JRC. (2012). *Harmonized world soil database (version 1.2)*. FAO.

Fernandez, C. J., Fromme, D. D., & Grichar, W. J. (2012). Grain sorghum response to row spacing and plant populations in the Texas coastal bend region. *International Journal of Agronomy*, *4*, 1–6. https://doi.org/10.1155/2012/238634

Gong, W., Yan, X., Wang, J., Hu, T., & Gong, Y. (2009). Long-term manure and fertilizer effects on soil organic matter fractions and microbes under a wheat-maize cropping system in northern China. *Geoderma*, *149*(3–4), 318–324. https://doi.org/10.1016/j.geoderma.2008.12.010

Guzha, A. C. (2004). Effect of tillage on soil micro-relief, surface depression storage and soil water storage. *Soil and Tillage Research*, *76*(2), 105–114. https://doi.org/10.1016/j.still.2003.09.002

Hiremath, S. M., Hebbi, B. S., & Halikatti, S. I. (2003). Performance of rabi sorghum as influenced by nitrogen and in situ soil moisture conservation practices in kharif sunnhemp for green manuring. *Karnataka J Agric Sci* 16: 216–219.

larbi, I., Hountondii, F., Annor, T., Agyare, W., and J. M. Gathenya. 2018. Spatio-temporal trend analysis of rainfall and temperature extremes in the vea catchment, Ghana. *Academic Open Access*, *6*(4), 87–98.

Kugbe, J. X., Mbawuni, A. M., & Agyiri, W. (2019). Growth, yield and yield components response of local sorghum varieties to nitrogenous fertilizer rates in Northern Ghana. *World Journal of Agriculture and Soil Science*. https://doi.org/10.33552/WJASS.2019.03.000574

Lipic, J., Kus, J., Slowinska-Jurkiewicz, A., & Nosalewicz, A. (2005). Soil porosity and water infiltration as influenced by tillage methods. *Soil and Tillage Research*, *89*(2), 210–220. https://doi.org/10.1016/j.still.2005.07.012

Lopez-Garrido, R., Deurer, M., Madejón, E., Murillo, J. M., & Moreno, F. (2012). Tillage influence on biophysical soil properties: The example of a long-term tillage experiment under Mediterranean rain fed conditions in South Spain. *Soil and Tillage Research*, *118*, 52–60. https://doi.org/10.1016/j.still.2011.10.013

Mundia, C. W., Secchi, S., Akamani, K., & Wang, G. (2019). A regional comparison of factors affecting global Sorghum production. the case of North America, Asia and Africa's Sahel. *Sustainability*, *11*(7), 21–35. https://doi.org/10.3390/su11072135

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. https://doi.org/10.1016/j.fcr.2012.02.020

Nelson, D. W., & Sommers, L. E. (1996). Methods of determination of total organic carbon (TOC) in soils and sediments. In A. L. Page (Ed.), *Total C, organic C and organic matter* (pp. 456–691 461). American Society of Agronomy, Soil Science Society of America, Ecological Risk Assessment Center, Office of Research and Development, US. Environmental Protection Agency, Las Vegas.

Ogbaga, C. C., Bajhaiya, A. K., & Gupta, S. K. Improvements in biomass production: Learning lessons from the bioenergy plants maize and sorghum. (2019). *Journal of Environmental Biology*, *40*(3), 400–406. 19. https://doi.org/10.22438/jeb/40/3/MRN-891.

Olugbemi, O., Aboyeji, C., Olofintoye, J., & Eifediyi, E. (2018). Growth and ethanol yield responses of sweet Sorghum [sorghum bicolor (l.) moench] varieties to nitrogen fertilizer rates. *Journal of Agricultural Sciences*, *13*(1), 67–81.

Rockstrom, J. (2003a). Water for food and nature in drought-prone tropics: Vapor shift in rain-fed agriculture. *Phil, Transactions R Society Land*, *358*(1440), 1997–2009. https://doi.org/10.1098/rstb.2003.1400

Rockstrom, J. P., Kaumbutho, P., Mwalley, A. W., Nzabid, M., Temesgen, L., Mawenyac, J., Barron, J., Mutua, S., & Damgaard, L. (2009). Conservation farming strategies in East and Southern Africa: Yields and rainwater productivity from on-farm action research. *Soil and Tillage Research*, *103*(1), 23–32. https://doi.org/10.1016/j.still.2008.09.013

Statistical Analysis System (SAS) Institute. (2002). *SAS/STAT user's guide* (6th). SAS Institute, Cary. pp. 112. Version 8.

Stone, L. R., & Schlegel, A. J. (2006). Yield-water supply relationship of grain sorghum and winter wheat. *Agronomy Journal*, *98*(5), 1359–1366. https://doi.org/10.2134/agronj2006.0042

Tekle, Y., & Zemach, S. (2014). Evaluation of sorghum (*Sorghum bicolor* (L.) Moench) varieties, for yield and yield components at Kako, Southern Ethiopia. *Journal of Plant Sciences*, *2*(4), 129–133. https://doi.org/10.11648/j.jps.201.40204.12

Tolk, J. A., & Howell, T. A. (2001). Measured and simulated evapotranspiration of grain sorghum with full and limited irrigation in three high plains soils. *Transactions. of Asae*, *44*, 1553–1558.

Twomlow, S. J., Steyn, J. T., & Du Preez, C. C. (2006). Dryland farming in southern Africa. chapter 19. In A. Gary, P. W. Peterson, W. A. Unger, & U. W. A. Payne (Eds.), *Dryland agriculture* (2nd., pp. 769–836). American Society of Agronomy. https://doi.org/10.2134/agronmonogr23.2ed.c19 Agronomy Monograph vol. 23.

Vincent, V., & Thomas, R. G. (1960). *An agricultural survey of southern rhodesia, part i agro-ecological survey*. Government Printers.

Wang, Y., Mi, G., Chen, F., Zhang, J., & Zhang, F. (2005). Response of root morphology to nitrate supply and its contribution to nitrogen accumulation in maize. *Journal. Plant Nutrition*, *27*(12), 2189–2202. https://doi.org/10.1081/PLN-200034683

Wani, S. P., Pathak, P., Jangawad, L. S., Eswaran, H., & Singh, P. (2003). Improved management of vertisols in the semi-arid tropics for increased productivity and soil erosion sequestration. *Soil Use Managemant*, *19*(3), 217–220. https://doi.org/10.1111/j.1475-2743.2003.tb00307.x

Zhang, Z., Christensen, M., Nan, Z., Whish, J. P. M., & Bell, L. W. (2019). Plant development and solar radiation interception of four annual forage plants in response to sowing date in a semi-arid environment. *Industrial Crops and Products*, *131*, 41–53. https://doi.org/10.1016/j.indcrop.2019.01.028