Water Conservation Science and Engineering
https://doi.org/10.1007/s41101-019-00067-4

ORIGINAL PAPER

Assessment of Effects of Zero and Conventional Tillage Practices on Soil Moisture and Wheat Grain Yield in Arid and Semi-Arid Land of Laikipia, Kenya

Mary W. Mutonga [1] · Emmanuel C. Kipkorir [2] · Wilson K. Ng'etich [3]

Received: 19 October 2018 / Revised: 29 January 2019 / Accepted: 28 February 2019

Abstract
Soil water conservation through tillage is one appropriate way of addressing soil moisture deficit in rain-fed agriculture. The influence of zero and conventional tillage on soil moisture and yield of wheat was investigated in arid and semi-arid lands (ASAL) of Laikipia County, during short rain season of 2015/2016 (September to February). Field trials were carried out with two tillage treatments, zero tillage (ZT) and conventional tillage (CT), with four varying sowing onset dates namely early (SD1), normal (SD2), late (SD3), and a control treatment with supplemental irrigation under normal sowing dates (WTSD2). The zero tillage fields used had been under the tillage practice for over 10 years while adjacent conventional tillage field was disturbed by plowing and harrowing. This was laid out in a randomized complete block design in split plot arrangement with three replicates. Undisturbed soil samples for gravimetric soil moisture determination were taken every 10 days from four depths (10 cm, 25 cm, 45 cm, and 60 cm) in the root zone during the entire growing season from each sub-plot. Irrespective of the sowing date, soil water content at the root zone between the two tillage practices and crop yields was significantly different at $p < 0.05$. The mean yield was 5.70 ± 1.08 ton/ha (CT) and 8.69 ± 0.54 ton/ha (ZT) in rain-fed trials. Supplemental irrigation trials for the two tillage practices had comparatively equal mean grain yield (12.91 ± 1.37 ton/ha (ZT) and 13.61 ± 0.46 ton/ha (CT)). It was concluded that zero tillage conserved moisture better leading to higher grain yield gap of up to 3 ton/ha.

Keywords Climate change · Infiltration · Moisture retention · Onset of rainfall · Root zone · Runoff

Introduction

Kenya faces numerous challenges against the need to increase food production to feed an exponentially increasing population, especially with the setbacks posed by the current enigma of climate change. Among the challenges affecting farming is soil water deficit and soil degradation. Soil water conservation through tillage is one appropriate way of addressing soil moisture deficit in rain-fed agriculture in arid and semi-arid lands (ASAL). The commonly used tillage practice in Kenyan ASAL which covers approximately 80% of the country is conventional tillage [1]. The farmers usually perform the plowing operation with a disc plow followed by one harrow or in some scenarios two harrow operations to attain a fine tilth for the seed. These operations expose the soil to the atmosphere increasing the rate of evaporation of soil water from the top profile. Pulverized soil particles are easily eroded and clog the water pores when it rains and together with the destroyed soil structure inhibit water infiltration and availability to the crop.

On the other hand, zero tillage which is rarely used especially in small-scale farming in Kenya, the farmer performs no mechanical operation (no cultivation) to the soil [2, 3]. The farmers use chemicals to control weeds [4], leaving crop residue from the previous harvest on the soil surface while plant roots remain in the soil. As a result, the undisturbed decomposing plant roots increase earthworm activity [5, 6], and the increase in organic matter in the soil creates larger pores in the soil causing it to hold moisture better [2].

✉ Mary W. Mutonga
mutongamary09@gmail.com

[1] Department of Agricultural and Biosystems Engineering, University of Eldoret, P. O Box 1125, Eldoret, Kenya

[2] Department of Civil and Structural Engineering, Moi University, P. O Box 3900, Eldoret, Kenya

[3] Department of Soil Science, University of Eldoret, P. O Box 1125, Eldoret, Kenya

Published online: 15 March 2019

Additionally, horizontal burrows from earthworm activities in the top layer improve the soil aeration while those penetrating deeper help channel rainwater to the lower soil layers [5]. This enhances moisture infiltration and storage from reduced evaporation and runoff, thus reducing the effect of soil water deficit to crop during the growing period [2].

Under the current condition of seasonal variability of rainfall, crop production has been declining due to soil moisture deficit at different stages of crop development under conventional tillage in ASAL in Kenya. According to Kaumbutho and Kienzle [4], soil degradation, declining crop yield, and increased cost of production are also among other challenges faced by farmers using conventional tillage. As a result, the practice of zero tillage is gaining acceptance especially among the large-scale farmers in ASAL in Kenya as is the case in the present study area of Laikipia.

ASAL areas are characterized by high variability of rainfall in time and distribution characterized by few rainfall days of high intensity [7–9]. Also, according to observations, rainfall is usually low and unreliable in ASAL areas [4]. Huho [10] notes that rainfall season in Laikipia has been marked by delayed onsets, decline in number of rain days, and increased rainfall intensities altering farming calendar with negative effects on crop yields. This variability affects the timing and relative length of growing period [11]. This is a major constraint in rain-fed farming because it affects water availability to the crop in the root zone leading to decline in crop yields [9, 11]. The crop grain yield loss is approximated to be up to 1 ton/ha [12, 13].

As observed, zero tillage can be an adaptation to climate change to mitigate the challenge of moisture deficit during the growing period which results in reduction of crop yield either by shortening the growing period from delayed onset or entire crop loss from a false start [12, 13]. However, even though zero tillage is becoming popular with indications of being effective [11], other studies have maintained that there is a need for further investigations on its effectiveness in low rainfall environments [14]. This study was therefore conducted to assess the effects of tillage practices (conventional tillage (CT) and zero tillage (ZT)) on soil water content and wheat crop yields in Laikipia East sub-county located in ASAL area.

Materials and Methods

Study Area

The study was carried out in Laikipia County (Fig. 1) which is classified as an ASAL area in Kenya with a major potential for wheat production.

It lies between latitudes 0° 17′ S and 0° 45′ N and longitudes 36° 15′ E and 37° 20′ E. The area experiences largely a bimodal rainfall pattern with the long rain season between March and May and the short rain season between October and November as illustrated in Fig. 2.

Annual rainfall averages 650 mm (Fig. 2), although it can be unreliable and characterized by highly variable onsets which can be delayed by up to 2 months in some seasons [4, 15]. The mean annual evapotranspiration (ETo) approximates 1452 mm (Fig. 2). Additionally, the area receives few rain days of very high intensity characteristic of such ASAL areas [10].

Experimental Site and Design

The study was carried out in Lengetia farm, Laikipia County (Fig. 1). The farm of approximately 4500 acres in area is located in a wheat-growing zone, and has been under zero tillage for over 10 years [4]. The dominant soil texture in the farm is clay soil.

The field trial was laid out in randomized complete block design in split plot arrangement during the short rain season of 2015/2016. Tillage treatment formed the main block factors in the split plots (zero tillage (ZT) and conventional tillage (CT)) while sowing dates representing the early, normal, and late sowing onsets (Table 1) formed the sub-plot factors randomized and replicated thrice on each of the split plot.

Sowing dates were determined using the onset of rainfall and rainfall depth criterion in AquaCrop model using historic daily rainfall data [1, 16] (Table 1). The onset dates were generated based on historical farmer's practice of sowing (to establish the normal (wet) planting date and sowing window), historical climatic data, and criteria for selection of dry sowing date(s) by the AquaCrop model. However, the Raes et al. [16] rainfall criterion was used with little adjustment due to the fact that accumulated rainfall of 40 mm was limited under ASAL climate. An accumulated rainfall depth of at least 10 mm over a period of 4 days was adopted as the adjusted criterion for defining onset. The adjustment was that germination was triggered by received rainfall of at least 10 mm for four consecutive days. This is the amount of rainfall that was required to raise the soil water content from wilting point to field capacity in a profile of 10 cm of the top soil.

From experience, the farmer's sowing window lies between 15 September and 15 October. The search window in AquaCrop was stretched by 15 days on both sides to between 1 September and 31 October to take care of chances of early onset or very late onset of rainfall which trigger the onset of sowing. The first date to be generated within the search window comprised the early (dry onset date) onset date. Then, the first generated onset date after 7 days from early sowing represented the normal sowing date, and finally, the first generated date after 7 days from the normal sowing date was considered as the late sowing date.

The four sowing onset dates (Table 1), representing the three onset dates under rain-fed condition, and one water

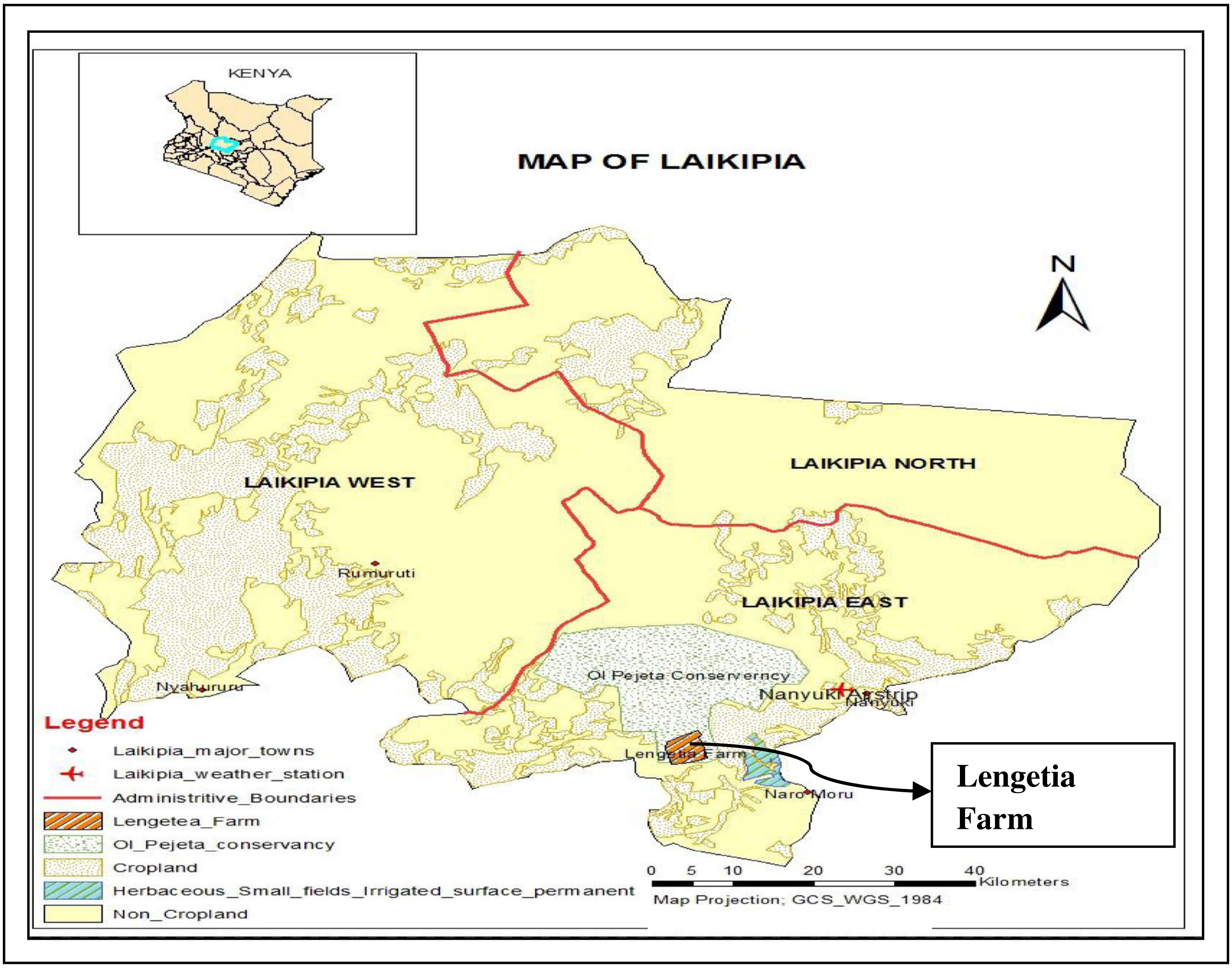

Fig. 1 Laikipia County map indicating location of the study area and major land uses in the county (source: Author 2016)

regime control treatment (with supplemental irrigation) were randomized among the sub-plots as one dry onset (sowing date one (SD1)), one normal onset (sowing date two (SD2)), one late onset (sowing date three (SD3)), and one normal onset under supplemental irrigation (water regime treatment (WTSD2)). The effect of rain days was not investigated because it was assumed that rainfall had a direct effect of raising the soil water content in the root zone and it was the sole source of water for rain-fed trials.

The sub-plots were 24 m^2 (4 m × 6 m) each in area consisting of 12 rows, 6 m long and 0.3 m between rows, separated by 1.5 m to ensure that the treatments in the plots were independent of each other. This is the spacing recommended for dry areas [4]. The total number of sub-plots was

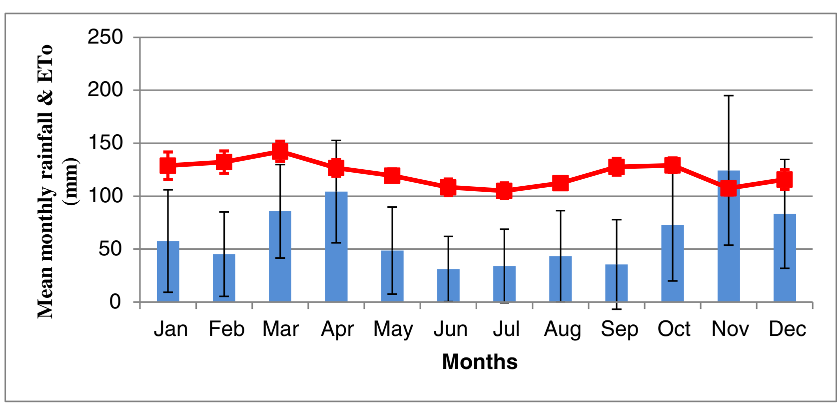

Fig. 2 Historical mean monthly ETo (line graph) and historical mean monthly rainfall distribution (bar graph) (for the period 1992–2015 and 1955–2015 respectively) indicating the two rainfall seasons (data from WRMA Ewaso Nyiro South). The error bars indicate standard deviation

Table 1 Sowing dates representing the three sowing season characteristics determined by onset of rainfall an adjustment of rainfall criterion in AquaCrop [16, 17]

Sowing date	Occurrence	Symbol	Sowing time characteristic	
			Onset time	Type of sowing
29 September	1st	SD1	Early	Dry
21 October	2nd	SD2	Normal	Wet
21 October	2nd	WTSD2	Normal (irrigated)	Wet
31 October	3rd	SD3	Late	Wet

24: two tillage treatments (ZT and CT (2TT)), by four onset-dates treatments (4SD) replicated thrice (3), i.e., (2TT × 4SD × 3 = 24).

Crop Management

Certified seed of wheat (*Triticum aestivum*) of the Kenya *Korongo* (KSRR-VIII) variety was sown in each sub-plot, based on the sowing dates in Table 1. This commercial wheat variety is new and rust resistant, classified as semi-dwarf, and was released in the year 2012 by Kenya Agricultural Research and Livestock Organization (KARLO), a National Plant Breeding Research Center in Kenya. The criteria used to select the variety for this research were based on plant breeder's information (KARLO, Njoro station), and farmers' experience recommending it as the best variety compared to other varieties in terms of bearing up periods of high water stress and resistance to rust and other diseases. Also, unlike other new varieties, it had a higher yield potential of 8.5 ton/ha reaching maturity at 120–130 days (http://www.wheatatlas.org/country/varieties/ken/0, accessed on 6 June 2016).

The crop management during the growing season was done according to the guidelines on spray timing of wheat crop [7]. The crop under the two tillage treatments was supplied with equal and recommended fertilizers/nutrients based on fertility analysis test results and nutrient recommendations for wheat crop [18]. The fertilizer application rates were 110 kg/ha diammonium phosphate (DAP) at planting and top dressing at early tillering with urea at a rate of 110 kg/ha. The timing of application and application rates were applied uniformly in each treatment.

The final grain yield was obtained at maturity by harvesting randomly three representative quadrants of one square meter (1 m^2) each, from each of the 24 sub-plots, dried to 13% moisture content, threshed, and weighed.

Soil Sampling Method

Two types of soil samples were collected: disturbed soil samples for textural analysis and undisturbed soil samples for soil water content determination (every 10 days) and bulk density determination. The field was traversed in a zigzag pattern and representative disturbed soil sample collected from eight points on the field from depth intervals of 0–25 cm, 25–45 cm, 45–65 cm, and 65–90 cm within 90 cm of the soil profile. The top 0–25 cm of the soil sample was also used for full fertility analysis for use in fertilizer recommendation.

A composite sample was obtained from mixing and quarter method on the eight sub-samples for the respective soil depth intervals. This method was used because it was convenient for a small field and fully represented the area.

Hydrometer method [19] was carried out to determine the mineral percent proportion of sand, silt, and clay particles; then, the textural class of the soil was derived using USDA textural triangle. Pedotransfer functions generated by soil texture available in soil hydraulic property calculator [20] were used to determine the water content at permanent wilting point (θ_{PWP}), field capacity (θ_{FC}), and at saturation (θ_{sat}).

Core samplers were used to collect undisturbed soil samples of known volume from four depths (10 cm, 25 cm, 45 cm, and 60 cm). The samples were collected at different points on all the sub-plots. Samples for soil water content determination were collected from each sub-plot and the respective four depths every ten (10) days for the entire growing period. Soil bulk density (g/cm^3) and soil water content were determined using gravimetric method [19]. The soil tests and analysis were carried out at the University of Eldoret soil science laboratory (texture analysis) and the Ministry of Transport and Public Works Laboratory at Nyeri (gravimetric soil water content).

Statistical Analysis

The soil water content and wheat grain yield data obtained were subjected to two tests of normality Kolmogorov-Smirnov test and Shapiro-Wilk test, but because the dataset was smaller than 2000 elements, the Shapiro-Wilk test results were used. Shapiro-Wilk test provides better power than the Kolmogorov-Smirnov test even after the Lilliefors correction [21]. Further on confirmation that the data was normally distributed, analysis of variance (ANOVA) and *t* test analysis were performed to evaluate the treatment effects using SPSS version 20 statistical software. The statistical test of significance was performed at 5% level of significance ($p < 0.05$).

Results and Discussion

The common approach of determining the effect of tillage on soil has been to evaluate tillage using crop yields and or water content http://www.agriculture.alberta.ca [2, 22]. A similar approach was adopted for this study.

Climate Data

The historic rainfall data of the study area is presented in Fig. 2 which also indicates the relationship between historic mean monthly evapotranspiration (ETo) and variable monthly rainfall in millimeter (mm). The error bars on Fig. 2 are indicative of the high variability in monthly rainfall all year round as reported [10]. The error bars on the line graph in Fig. 2 similarly represents the standard deviation in ETo which is conservative compared to the highly variable rainfall. The received rainfall per decade for the entire growing period during the field trials is indicated in Fig. 3. Each of the treatment for the three sowing dates received the following seasonal rainfall amount: SD1 (520 mm), SD2 (483 mm), WTSD2 (483 mm), and SD3 (467 mm).

Soil Properties

The result of textural analysis indicates that the soil is clay with varying proportions of clay content (Table 2). From observations on the field, the soil cracks heavily when dry but closes up and very sticky when wet. This is evidence of the high clay content in the soil which influences strongly soil water behavior because of its ability to adsorb and retain water and cation [5] a desirable characteristic in such dry areas with low rainfall. The total available water (TAW) ranged between 134 and 124 mm/m (Table 2). The bulk density was within the range of 1.2 g/cm^3 for clay and 1.3 g/cm^3 for clay loam.

Soil Moisture Variations in Zero and Conventionally Tilled Fields

Zero tillage split plots maintained higher moisture contents at all times during the growing season compared to conventionally tilled plots (Figs. 4, 5, 6, 7, 8, 9 appended for reference) respectively for SD1 (0–25 cm), SD1 (0–60 cm), SD2, SD3, and WTSD2. The Shapiro-Wilk normality test results which provide better power than the Kolmogorov-Smirnov test [21] indicated that the soil water content data had normal distribution ($p > 0.05$) both at the entire root zone up to 60 cm of the soil profile considered (Table 3) and the top soil profile (0–25 cm) (Table 6 appended). Further, a test of significance was performed on both the top 25 cm of the soil profile for all the sowing dates and the entire root zone in a soil profile of 60 cm. Although there was variation in soil water content at the top 25 cm, the variation was only significant for SD1 ($p < 0.05$) but not significant under SD2, SD3, and WTSD2 at $p < 0.05$ (Table 4).

Considering the entire root zone in a profile of 60 cm, both rain-fed and irrigated trial plots had significant variation in soil water content (mm) at $p < 0.05$ (Table 5). The results (Table 5) suggest the significant role of zero tillage in moisture retention.

From field observation during the field trials, zero tillage fields experienced reduced runoff. This is as a result of increased surface roughness due to the presence of crop residue on the ground that in turn increases the opportunity time for infiltration. This enhanced infiltration rates in zero-tilled fields and thus the observed high water content. On the contrary, conventionally tilled fields were observed to experience high runoff and erosion of the loose fine soil particles which seal the surface hindering infiltration.

Although the farm had been under zero tillage for over 10 years [4], one season of plowing and harrowing (in conventional plots) resulted in significant soil moisture difference at $p < 0.05$ (Table 5). This is consistent with the findings of [12]. This affirms the importance of conservation tillage

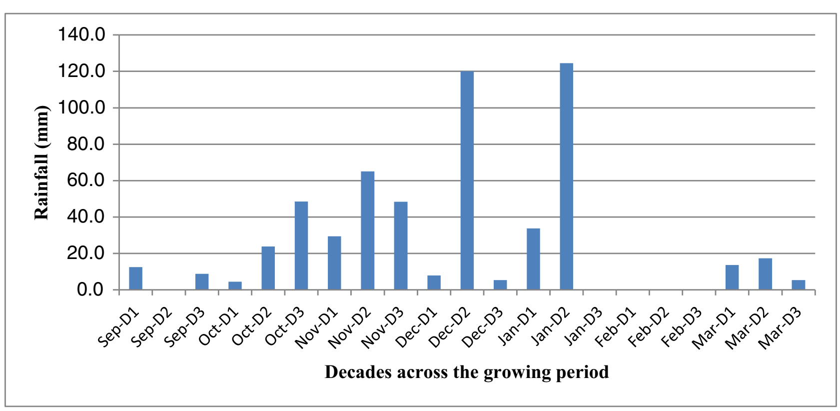

Fig. 3 Bar graph indicating received rainfall (mm) grouped in decades for the entire growing period. Measured using rain gauge installed on site

Table 2 Major physical soil characteristics of the soil of the trial site (0–90 cm)

Profile depth	Soil texture				Moisture content				
(cm)	Clay (%)	Silt (%)	Sand (%)	Textural* class	FC* (Vol%)	PWP* (Vol%)	SAT* (Vol%)	TAW* (mm/m)	Bulk density (g/cm^3)
0–25	56	23	21	Clay	45.8	32.4	54	134	1.22
25–45	45	21	34	Clay	37.3	25.0	51.8	124	1.28
45–65	47	23	30	Clay	39.2	26.3	52.4	129	1.26
65–90	23	29	36	Clay loam	32	19	50	130	1.32

FC field capacity, *PWP* permanent wilting point, *SAT* saturation, *TAW* total available water, K_{sat} saturated hydraulic conductivity

*Derived properties using pedotransfer functions (Saxton et al. 1986) (source: Author 2016)

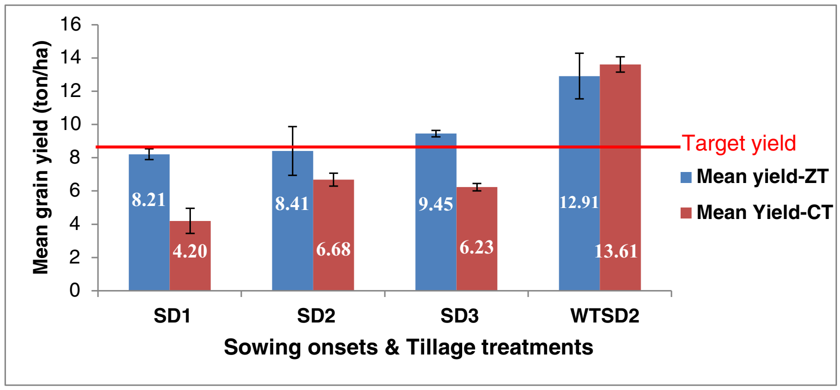

Fig. 4 Bar graph indicating the obtained mean wheat grain yield (ton/ha) among the varied sowing onsets in zero (ZT) and conventional tillage (CT). The error bars show standard deviation in grain yield. The red line indicates the plant breeders target yield of 8.50 ton/ha

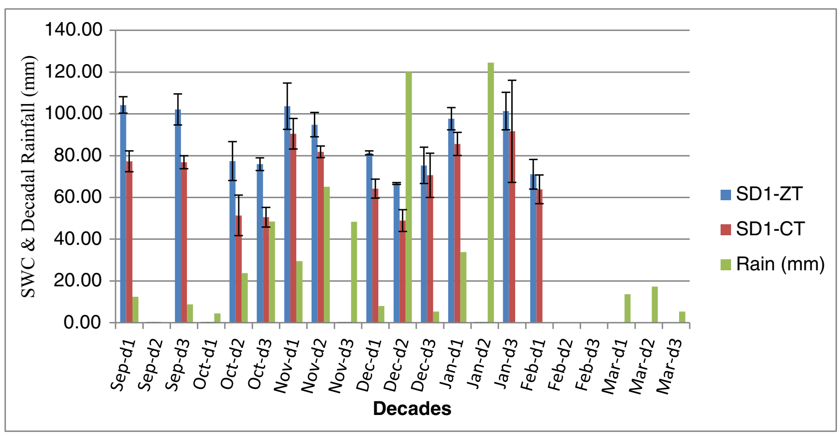

Fig. 5 Bar graph showing the measured soil water content at the topsoil (0–25 cm) in zero (ZT) and conventional tillage (CT) and the received rainfall (mm) within the decades (10-day interval) for the entire growing period (in SD1 Plot). The error bars indicate standard deviation

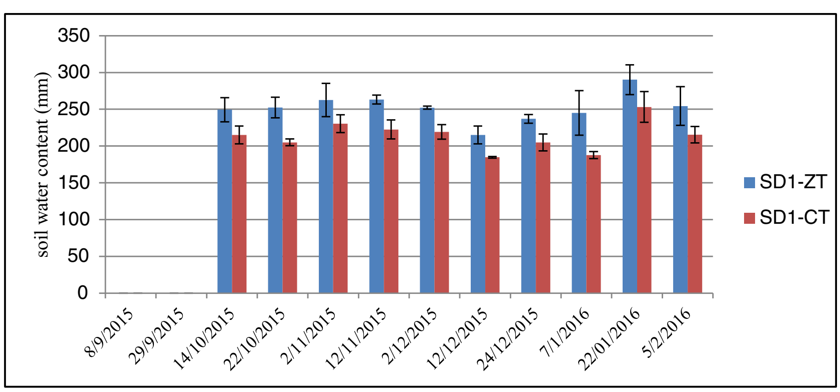

Fig. 6 Bar graph indicating variation in measured soil water content at the root zone (0–60 cm) between ZT and CT (in SD1) in the respective dates. The error bars indicate standard deviation

Fig. 7 Bar graph indicating variation in measured soil water content at the root zone (0–60 cm) between ZT and CT (in SD2) in the respective dates. The error bars indicate standard deviation

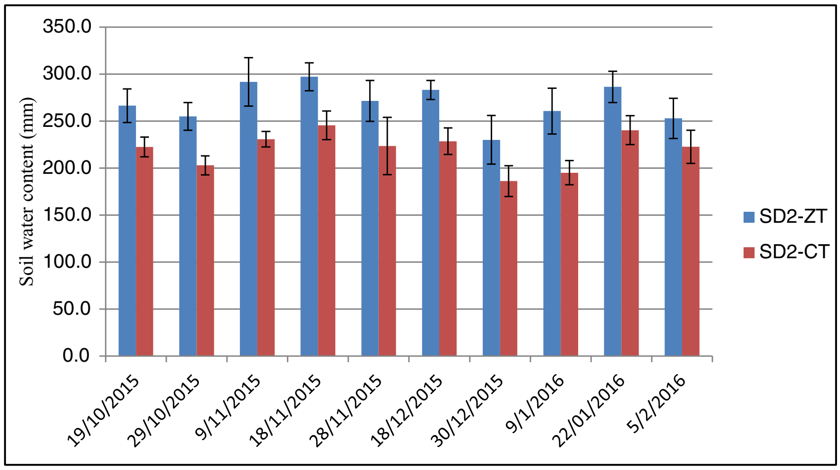

Fig. 8 Bar graph indicating variation in measured soil water content at the root zone (0–60 cm) between ZT and CT (in SD3) in the respective dates. The error bars indicate standard deviation

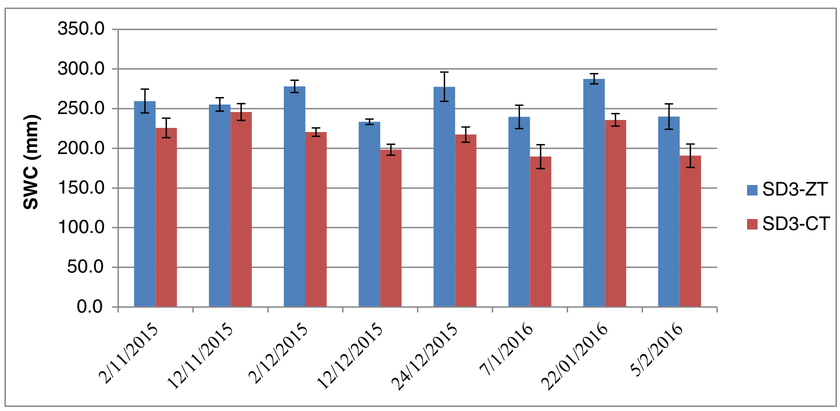

Fig. 9 Bar graph indicating variation in measured soil water content at the root zone (0–60 cm) between ZT and CT (in WTSD2) in the respective dates. The error bars indicate standard deviation

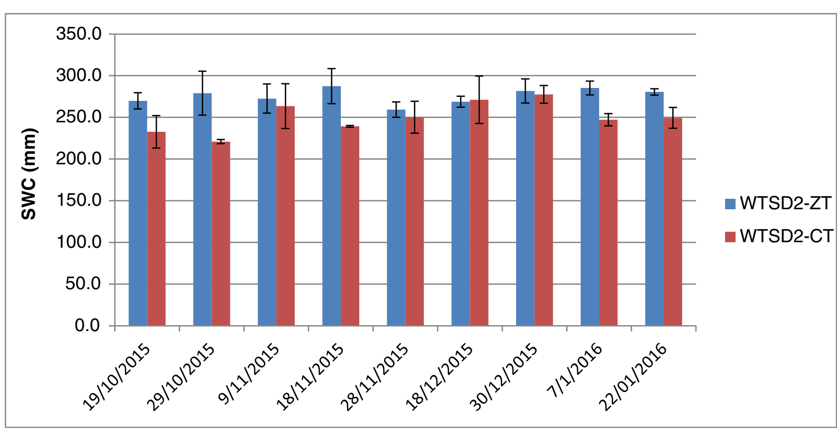

Table 3 Tests of normality for soil moisture content in the root zone (0–60 cm) considering each independently

Treatments	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SD1-ZT	0.236	6	0.200*	0.937	6	0.634
SD1-CT	0.286	6	0.136	0.890	6	0.319
SD2-ZT	0.293	6	0.116	0.853	6	0.166
SD2-CT	0.249	6	0.200*	0.923	6	0.529
SD3-ZT	0.285	6	0.138	0.827	6	0.101
SD3-CT	0.212	6	0.200*	0.891	6	0.325
WTSD2-ZT	0.202	6	0.200*	0.929	6	0.572
WTSD2-CT	0.207	6	0.200*	0.948	6	0.724

*. This is a lower bound of the true significance

[a] Lilliefors significance correction

Table 4 Difference in top soil water content (0–25 cm)

Treatments	Levene's test for equality of variances		*t* test for equality of means				
	F	Sig.	T	df	Sig. (2-tailed)	Mean difference	Std. error difference
SD1	0.004	0.947	2.733	22	0.012*	16.53	6.05
			2.733	21.874	0.012*	16.53	6.05
SD2	0.230	0.637	1.893	18	0.075	13.02	6.88
			1.893	17.743	0.075	13.02	6.88
SD3	0.008	0.928	1.630	14	0.125	9.42	5.78
			1.630	13.981	0.125	9.42	5.78
WTSD2	0.989	0.335	0.170	16	0.867	0.99	5.84
			0.170	14.535	0.867	0.99	5.84

*There is significant difference in top soil water content at 5% level of significance

Table 5 Soil moisture variation as influenced by tillage treatments (0–60 cm)

Independent variables (field plots)		Test for equality of variances		*t* test for equality of means		
Zero tilled	Conventionally tilled	F	Sig.	Sig. (2-tailed)	Mean difference	Std. error difference
SD1	SD1	0.126	0.727	0.000*	38.32	8.80
				0.000*	38.32	8.80
SD2	SD2	0.086	0.772	0.000*	49.71	8.94
				0.000*	49.71	8.94
SD3	SD3	0.001	0.977	0.001*	43.48	10.32
				0.001*	43.48	10.32
WTSD2	WTSD2	2.453	0.137	0.002*	25.82	6.78
				0.003*	25.82	6.78

*There is significant difference in soil water content at 5% level of significance within the entire soil profile (0–60 cm) considered

Table 6 Normality test on soil water content at top 0–25 cm of the soil profile considering each independently

Treatments	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
SD1-ZT	0.202	8	0.200*	0.886	8	0.215
SD1-CT	0.219	8	0.200*	0.893	8	0.248
SD2-ZT	0.160	8	0.200*	0.971	8	0.905
SD2-CT	0.212	8	0.200*	0.948	8	0.695
SD3-ZT	0.169	8	0.200*	0.958	8	0.789
SD3-CT	0.158	8	0.200*	0.964	8	0.851
WTSD2-ZT	0.152	8	0.200*	0.985	8	0.983
WTSD2-CT	0.154	8	0.200*	0.951	8	0.721

*This is a lower bound of the true significance

[a] Lilliefors significance correction

practices (zero tillage) as an alternative tillage practice and an adaptation to climate change.

Even after a rainfall event (Fig. 5), zero tillage maintained higher surface soil moisture as well as soil water content at the root zone (60 cm profile) (Figs. 5, 6, 7, 8, 9 (appended)), Tables 4 and 5).

There are several explanations to this all pointing to improvement in soil hydraulic properties [1, 23, 24]. For instance, due to the undisturbed nature of the soil and continued use of chemical weeding in zero tillage, the plant roots remain in the soil and the plant's residue remain on top of the soil. This together with the increase in organic matter in the soil enhances the soil structure formation and creates larger pores in the soil causing it to hold moisture better [2]. Additionally, because of better water infiltration and reduced evaporation [1, 24], higher water content was observed in zero tillage than conventionally tilled soils [2] (Table 6).

The decrease in evaporation and the greater ability to store moisture under zero tillage produces greater water reserves which support the crop during periods of drought stress. On the contrary, the intensive operation and manipulation of the soil under conventional tillage results to soil pulverization and destruction of soil structure. This combined with reduced surface roughness from absence of crop residue on the soil surface leads to high runoff and erosion. There is also increased evaporation from exposed (by plowing) soil and illuviation of fine (pulverized) soil particles. The result is surface sealing and crusting which reduce the infiltration and water holding capacity of the soil [9]. This explains the observed low soil water content in conventional tillage.

Tillage Effect on Grain Yield

The mean grain yield was significantly variable ($p < 0.05$) under conventional tillage and below the plant breeders target yield of 8.50 ton/ha as compared to zero tillage (Fig. 4).

The total mean yield for rain-fed wheat crop was 5.70 ± 1.08 ton/ha and 8.69 ± 0.54 ton/ha in conventional and zero tillage respectively. The large yield gap (up to 3 ton/ha) between the attained mean yield in rain-fed conventional and zero tillage plots shows the high potential of zero tillage in rain-fed agriculture. However, this potential is yet to be tapped. This yield gap can be interpreted as an inefficient soil water use/storage in conventional tillage as compared to zero tillage.

The plant bleeders target yield is usually assumed attainable under optimal conditions of soil water content and soil fertility. The crop under the two tillage treatments was supplied with equal and recommended fertilizers/nutrients based on fertility analysis test results and [18] nutrient recommendations for wheat crop. Therefore, the crop was considered to be grown under no fertility stress. Additionally, the crop received a similar crop management practice of weeds, diseases, and pest control. In view of this, the only limiting factor to production, which would contribute to this yield gap, was soil water availability to the crop.

The high yield in zero tillage (8.69 ± 0.54 ton/ha) which is slightly above the target yield (8.50 ton/ha) signifies improved production in zero tillage irrespective of the sowing date. Additionally, the comparatively equal mean grain yield (12.91 ± 1.37 ton/ha (ZT) and 13.61 ± 0.46 (CT) ton/ha) in water regime trials (Fig. 4) confirm the potential of the area for wheat production with sufficient soil water content and no fertility stress. It also confirms that the yield gap of up to 3 ton/ha was due to soil moisture deficit during the growing period.

Conclusion

Soil water conservation is necessary in rain-fed agriculture during land preparation and crop growth in ASAL areas due to climate variability which affect the amount and timing of rainfall during the growing season.

The tillage practices and timing of onset of rainfall season (assumed to mark the onset of the sowing period) have an influence on soil water conservation, its availability to crop, and resultant crop yields in the ASAL Laikipia East sub-county. Zero tillage conserved moisture better leading to higher yield of 8.69 ± 0.54 ton/ha than conventional tillage yields of 5.70 ± 0.1.08 ton/ha. The comparatively equal mean grain yield (12.91 ± 1.37 ton/ha (ZT) and 13.61 ± 0.46 ton/ha (CT)) in no water stress trials confirms the potential of the area for wheat production with sufficient soil water content and no fertility stress. Zero tillage is recommended for use by farmers in the ASAL areas as an adaptation to climate change and a strategy to optimize soil water conservation and thus maximize crop yield.

Acknowledgements Mr. L. Sessions (Proprietor, Lengetia Farm Ltd) and the entire management and staff of Lengetia farm Ltd. are acknowledged for giving access to set up the field trials in their farm and continued support during the entire period of the study.

References

1. Potter KN, Torbert HA, Morrison JE (1995) Tillage and residue effect on infiltration and sediment losses on vertisols. Am Soc Agric Eng 38:1413–1419
2. Coleman C (2003) What are the effects of no-till farming on soil moisture and soil temperature compared to conventional tillage in Rice County Kansas? Cantaurus 11(May):2–4
3. Tripathi R, Raju R, Thimmappa K (2013) Impact of zero tillage on economics of wheat production in Haryana. J Agric Econ Res Rev 26(1):101–108
4. Kaumbutho P, Kienzle J (eds) 2007. Conservation agriculture as practiced in Kenya: two case studies. African conservation tillage network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations, Nairobi
5. Birkas M, Jug D, Kisic I 2014 Book of soil tillage. Szent University Press, p 322. ISBN: 978-963-269-447-4
6. Jordan D, Stecker VN, Cacnio-Hubbard FL, Gantzer CJ, Brown JR (1997) Earthworm activity in no-tillage and conventional tillage systems in Missouri soils: a preliminary study. Soil Biology and Biochemistry. In: 5th international Symposium on Earthworm Ecology, May–April 1997, 29(3):489–491. https://doi.org/10.1016/S0038-0717(96)00038-7
7. Home Grown Cereal Authority, (HGCA) (2016) Wheat disease management guide. Agriculture and Horticulture Development Board 2016 (AHDB) and (HGCA). Retrieved on 8th August, 2016 from. https://cereals.ahdb.org.uk/publications/2016/february/23/wheat-disease-management-guide.aspx
8. Karuma A, Mtakwa P, Amuri N, Gachene K, Gicheru P (2014) Enhancing soil water content for increased food production in semi-arid areas of Kenya: results from an on-farm trial in Mwala District, Kenya. J Agric Sci 6(4):125–134. https://doi.org/10.5539/jas.v6n4p125 Accessed 03 Mar 2015
9. Rockstrom J, Barron J, Fox P (2003) Water productivity in rain-fed agriculture: challenges and opportunities for smallholder farmers in drought prone tropical agroecosystem. CABI, IWMI, Wallingford
10. Huho J, Ngaira J, Ogindo H, Masayi N (2012) The changing rainfall pattern and the associated impacts on subsistence agriculture in Laikipia East District in Kenya. J. Geogr. Reg. Plann 5(7):198–206. https://doi.org/10.5897/JGRP12.018
11. Kijne J, Barron J, Hoff H, Rockström J (2009) Opportunities to increase water productivity in agriculture with special reference to Africa and South Asia: report prepared by Stockholm Environment Institute, for Swedish Ministry of Environment presentation at CSD 16, New York 14 May 2009. Stockholm Environment Institute, Stockholm, pp 1–48
12. Chandna P, Hodson DP, Singh UP, Singh AN, Gosain AK, Sahoo RN, Gupta RK (2004) Increasing the productivity of underutilized lands by targeting resource conserving technologies-A GIS/remote sensing approach a case study of Ballia District, Uttar Pradesh , in the Eastern Gangetic Plains. CIMMYT, Mexico.D.F
13. Sen A. *et al.* 2014. Zero tillage, a boon for wheat in rice, wheat cropping system. www.bhu.ac.in/agriculture/zero_tillage.html. Accessed 9 Dec 2015
14. Rockstrom J, Kaumbutho P, Mwalley J, Nzabi AW et al (2009) Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. Soil Tillage Res 103:23–32
15. Ojwang GO, Agatsiva J, Situma C (2010) Analysis of climate change and variability risks in the smallholder sector: case studies of the Laikipia and Narok Districts Representing Major Agro-ecological Zones in Kenya. FAO, Rome, pp 1–69
16. Raes D, Sithole A, Makaru A, Millford J (2004) Evaluation of first planting dates recommended by criteria currently used in Zimbabwe. J Agric For Meteorol 125:177–185
17. Raes D, Steduto P, Hsiao TC, Fereres E (2012) AquaCrop Reference manual (Version 4.0). Retrieved 2nd February, 2015 from http://www.fao.org/nr/water/aquacrop.html
18. Steduto P, Hsiao TC, Fereres E, Raes D (2012) Crop yield response to water. FAO Irrigation and Drainage Paper No. 66. FAO, Rome
19. Okalebo J, Gathua W, Woomer P (2002) Laboratory methods of soil analysis and plant analysis: a working manual. TBSF UNESCO. EPZ Publishers, Nairobi
20. Saxton KE, Rawls WJ, Romberger JS, Papendick RI (1986) Estimating generalized soil-water characteristics from texture. Soil Sci Soc Am J 50(4):1031–1036
21. Ghasemi A, Zahediasl S (2012) Normality tests for statistical analysis: a guide for non-statisticians. Int J Endocrinol Metab 10(2): 486–489. https://doi.org/10.5812/ijem.3505
22. Chaghazardi HR, Jahansouz MR, Ahmadi A, Gorji M (2016) Effects of tillage management on productivity of wheat and chickpea under cold, rain-fed conditions in Western Iran. J Soil Tillage Res 162:26–33. https://doi.org/10.1016/j.still.2016.04.010 Elsevier B.V
23. Araya T et al (2011) Effects of conservation agriculture on runoff, soil loss and crop yield under rain-fed conditions in Tigray, Northern Ethiopia. Soil Use Manag 27:404–414
24. Araya T, Cornelis WM, Nyssen J, Govaerts B, Getnet F, Bauer H, Amare K, Raes D, Haile M, Deckers J (2012) Medium-term effects of conservation agriculture based cropping systems for sustainable soil and water management and crop productivity in the Ethiopian highlands. Field Crop Res 132:53–62