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Effect of Reduced Tillage and Crop Residue Ground Cover on Yield and Water Use Efficiency of Sorghum (*Sorghum bicolor* (L.) Moench) Under Semi-Arid Conditions of Ethiopia

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Abstract: Reduced tillage and maintenance of ground cover with crop residues may increase water availability to the crop in semi-arid areas of Ethiopia. Conventional, tied-ridging and zero-tillage were compared with 0, 3 and 6 mg haG^{1} of tef straw applied after tillage. The interaction of tillage and straw application rate was significant for grain yield with 70 and 46% increases in yield with 3 mg haG^{1} of straw applied for conventional and zero tillage respectively, but yield with tied-ridging was not affected by straw application. The main effect of tillage on yield was not significant. Mean stover yield was also increased with straw application. Mean soil water throughout the season was nearly 20% more with tied-ridging than with other tillage practices and about 16% more with 3 mg haG^{1} straw applied as compared to no straw applied. Grain produced per unit of water used increased linearly with straw application rate and was less for zero tillage and for tied-ridging or conventional tillage. Tied-ridging is the most promising tillage practice and ground cover with crop residues is necessary to achieve acceptable yield with zero tillage.

Key words: Conservation tillage % reduced tillage % tef straw

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench.) is one of the leading traditional food crops of Ethiopia. Sorghum is grown in Ethiopia in 12 of the 18 agro-ecological zones. It ranks third in the country following teff and maize in total production and second to teff in its injera (national bread) making quality. Sorghum is grown mainly as a rainfed crop in the semi-arid areas. In these areas, sorghum production is being limited by water stress due to low and variable rainfall between and with the seasons. Sorghum yields vary considerably between years and show a close dependence on rainfall. The traditional major dry land crops like sorghum in semi-arid areas can be characterized as the most popular crop in the areas receiving low amount of rainfall, which is highly variable and erratic [1]. Its high demands as well as its suitability for dryland areas of the country have justified the high national priority accorded to the crop [2].

In Ethiopia crop production is mainly practiced under rain fed conditions. Substantial parts of the most important crop producing areas of Ethiopia fall within the semi-arid parts. As a result crops experience moisture stress at any time during their growth stage [3].

Dry land agriculture is highly dependent on aberrant rainfall as the only source of water. Further more, the actual proportion of rainfall available for plant growth depends on the infiltration rate of the surface soil profile. More over this infiltration rate depends on the soil type and the soil surface treatment. The soil types in semi-arid areas of Ethiopia are also diverse, most of them shallow and with low organic matter content, resulting in poor water holding capacity. As a result precipitation is less likely to be available to the crop, thus water conservation is a unique location specific practice [4].

The dryland areas are largely neglected sectors in agriculture of Ethiopia. Technology for these areas has been limited or lacking; yet paradoxically, the future of the expansion of Ethiopia's food production is in these areas. Despite this, the dryland areas have become concentrations of rural poverty [5].

The first step to improve agricultural production in the dryland areas is to develop water-harvesting techniques and then use the limited water efficiently.

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The most efficient and cheapest way of conserving rainfall is to hold it *in-situ*. Evaporation loss can also be reduced greatly if rainfall is stored in the soil to make it readily available to plants rather than in structure with a free water surface. Practices that conserve water received as rainfall, greatly improve the potential for success in dry land areas and such methods are also economically feasible to resource poor farmers than *ex-situ* water management methods [6, 7].

Several research activities were carried out and several efficient soil and water management practices were identified in sub-sahran Africa [2, 8, 9].

To improve dryland production practices for this region, a quantitative understanding of crop water use through the growing season as affected by different tillage systems and mulch management as means of *in-situ* water harvesting is essential . The paper describe the effect of these management practice on soil water storage and on the grain yield and water use efficiency of sorghum in the semi-arid region of Central Rift Valley of Ethiopia.

MATERIALS AND METHODS

Experimental sites: The experiment was conducted during the July to October rainy season of 2003 at Melkassa Research Center (MARC). The Center is located 15 km south-east of Nazareth in the semi-arid region of the Central Rift Valley of Ethiopia at 8° 24'N latitude and 39° 12'E longitude and at an elevation of 1550 m above sea level (m.a.s.l.). The site receives 763 mm mean annual rainfall but with much variation in distribution and amount, 70% of which occurs between the months of May and September. Late onset of rains, intermittent periodic dry spells and early cessation of rains are common causes of fluctuating annual production with occasional drastic reduction in crop yields [10]. The maximum and minimum annual mean temperatures are 28 and 14°C, respectively [10].

Total growing season rainfall from June to October was above the long-term average in 2003 (Fig. 1), but below average in July and October, considerably above average during June and near average in August. The crop did not experience serious drought except for a hot dry spell from late September to October, which caused incipient wilting on several occasions.

According to Ministry of Agriculture [11], the agro-ecology of the area is characterized under sub-moist, mountain and plateau, tepid to cool (SM2-5) based on the growing season, temperature and altitude of the area. There is high coefficient of variability (usually >30%) with regard to quantity, onset and cessation of rainfall. Occasional strong wind and high evapotranspiration due to high temperature that is normally above 25°C during the rainy season exacerbate the situation.

The soil type at the experimental site is a well-drained silty clay loam soil largely developed from volcanic parent material. The soil texture for this area is variable with typical ranges of 50%, 18% and 32% silt, sand and clay in texture, respectively [12].

Available soil water was between 34.04% at (-0.03 MPa) and 16.74% at (-1.5 MPa) on dry weight basis. The average bulk density is 1.13 g cm^{-3} from 0-90 cm soil depth. The soil was slightly alkaline as pH in water (1:2.5 soil water ratio) ranged from 7.4-7.6, an optimum range for availability of major nutrients (Table 3). Organic carbon contents were 0.31, 0.28 and 0.26% and total N contents were 0.08, 0.11 and 0.11% in 0-30, 30-60 and 60-90 cm soil depths, respectively. Normally the total nitrogen was medium and the organic carbon amount was very low in the soil. Available phosphorus (Olsen method) was 2.6, 1.55 and 1.26 mg kg^{-1} in 0-30, 30-60 and 60-90 cm soil depths, respectively, which is very low P availability for crop production.

Experimental design and treatments: Treatments consisted of a factorial combination of three levels of tef straw mulch (0, 3 and 6 mg ha^{-1} of tef straw) and three tillage systems (conventional, zero-tillage and tied ridge). The treatments were replicated three times in a single split plot design wherein tillage treatments were allocated to main plots and mulch levels to sub-plots. Each subplot was 6 m and 7.5 m with 10 rows spaced at 75 cm and with a plot area of 45 m^2. The outermost rows at both sides of the plots and 0.5 m row length at each end of the rows were considered as border. Second and third rows at one side of the plot were designated as sampling rows and the fourth row served as guard row for the sampling rows. Therefore, plot biomass and grain yield was measured for an area of 5 m long and 3.75 m wide (18.75 m^2).

Experimental procedures: All the treatments other than the zero tillage were cross-ploughed by oxen-drawn plough (farmer's practice) to prepare the seedbed. In tied ridged treatments, 35 cm high ridges were constructed manually 75 cm apart and cross-tied with soil bunds across the ridges at about every 6 m ridge length (length of sub-plots). In the zero-tillage treatment, weeds were manually removed before planting and a slot or narrow furrow was made manually to place fertilizer and seed, without any preparatory tillage. The sorghum variety

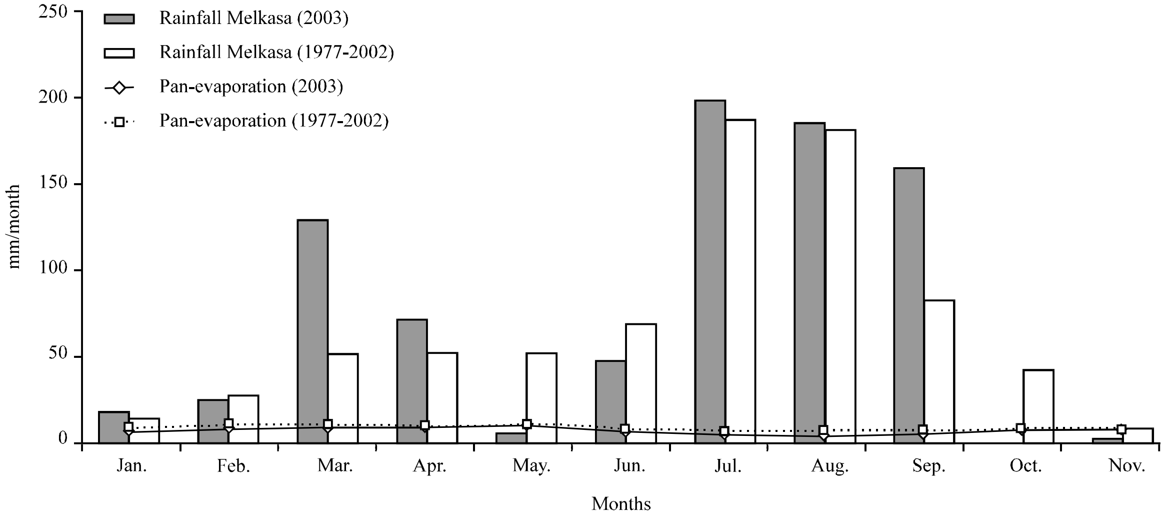

Fig. 1: Monthly and mean monthly precipitation, pan evaporation, maximum and minimum temperature at Melkassa (2003) and from 1977-2002

Meko, an early maturity type (60-70 days to anthesis), was planted on 8 July 2003. Two seeds were placed at 15 cm intervals between plants in rows and sorghum seedlings were thinned to one plant per hill 15 days after emergence to ensure the targeted population (88,888 plants per ha). The tef straw was shredded and spread manually as per mulch treatments in respective sub-plots at about the five-leaf stage of the crop right after thinning.

The experimental area was hand-weeded 2 weeks after germination and again about 30 days after crop emergence during cultivation of the conventional tillage treatments. Maintenance of the tied ridges to sustain more or less equal volume of furrow area was performed by making ridge on the previous furrow and re-tying the closed end of the cross-ties and this was performed 30 days after crop emergence at the initial growing point differentiation stage (GS-3).

Fertilizer was applied to the trial site uniformly at the rate of 41 kg N haG^{1} and 20.1 kg P haG^{1} using Urea and Diammonium Phosphate, respectively. One half of the N and all of the P were banded 5 cm below and 5 cm away the rows as a basal application and the remaining 20.5 kg N haG^{1} was side-dressed during cultivation at 30 days after emergence.

Sampling and measurements:

Crop data: Initial stand count after thinning and final stand counts were recorded by counting the actual number of plants in the net plot area. Grain yield and above ground biomass per plot was determined by harvesting all plants (inclusive of plants sampled for yield components). Grain yield was adjusted to 12.5% moisture content. Sorghum stover was harvested at the ground surface level and sun-dried to a constant weight for 3-4 weeks. Total above ground dry biomass, which included stover and whole panicles, were used to obtain biomass yield. Harvest index (HI) values were computed as the ratio of the grain yield to dry matter yield per plant from the respective treatments.

Soil moisture: *In-situ* soil water content up to a depth of 90 cm was measured since the deepest wetting front was 82 cm from the top. Soil moisture in 30 cm increments within the soil profile was determined gravimetrically for each plot in the central row in two replications using a core sampler. Soil water data were recorded at various growth stages from planting until the physiological maturity of the sorghum crop. Gravimetric soil water content was converted to a volumetric basis using bulk densities of soil cores taken from each depth increment [13].

Water use and water use efficiency: Crop water use (evapotranspiration, ET) was calculated from rainfall (R) and ( ) S) is the change in the soil water profile or soil water storage to a depth of 90 cm at intervals of 30 cm depth for the different periods of crop development i.e. from emergence to GS3, GS3 to GS5, GS5 to GS7 and from GS7 to GS9 was monitored and calculated by subtracting soil water content at the end of each seasonal segment from soil water content at the beginning of the segment for respective growth stages during the

Table 1: Main effects of tillage and mulch rate on initial and final plant stand counts after thinning and at harvest of sorghum per plot (22.5m^2) at Melkassa in 2003

Treatments	Initial stand count	Final stand count
*Tillage systems		
CT	178.39	171.90
ZT	177.37	163.50
TR	178.23	164.50
Sem ±	1.58	3.55
LSD$_{0.}$	ns	ns
Mulch rate (mg ha^{-1})		
0	177.80	166.80
3	178.30	167.04
6	177.60	166.43
Sem ±	0.94	0.94
LSD$_{0.05}$	ns	ns
CV (%)	1.60	1.71

ns - not significant
*Conventional tillage (CT); Zero-tillage (ZT); Tied ridging (TR)

experimental period. This method of ET calculation combines crop transpiration (T) and soil water evaporation (E), assuming no or negligible losses as runoff and drainage below the root-zone [13].

Water use efficiency (dry matter production in above ground biomass and grain yield per unit of water used) was determined immediately before harvesting using ET between the first sampling dates of soil water content and at different growth stages of the crop depending on the growing season and harvest day of the crop.

Statistical analysis: Trial data were subjected to the analysis of variance appropriate to experimental design [14]. Least significant differences were used for means separation at the 0.05 or 0.01 probability levels. Those variables that violated the assumption of analysis of variance were transformed using the standard procedure to equalize the variances. Correlation and regression analysis were performed between and / or among total seasonal water use, yield and yield components of the crop.

RESULTS AND DISCUSSION

Stand count: Crop establishment, as an important parameter was measured to understand the basis of crop performance as affected by treatments. Stand establishment often reflects the combined effect of soil property change and tillage performance. A uniformly and rapidly emerging crop is basic to successful crop production.

The initial and final stand count of sorghum crop was not affect by the main effects of tillage and mulch rates as well as by their interaction effect. However, poor seedling performance was observed on the zero-till plots. Less number of plant was obtained initially due to poor stand establishment of the variety used. There was a non significant 4.5% greater plant population at maturity on the conventional tilled as compared to tied ridged and zero tilled treatments (Table 1). Similarly Dabney *et al*. [15] reported 15% reduction in sorghum stand density with zero-tilled. For all treatments, mean plant population was less at harvest than following emergence due to mortality.

Grain yield: Grain yield is the important component of plant performance under a set of growing conditions. Any physiological or agronomic parameter at a given stage of growth would be of further use only when its effect is reflected on yield either way. Grain yield is a function of HI and dry matter production [16].

Mulch rate and the mulch by tillage interaction significantly affected grain yield, but the tillage effect was not significant (Table 2). Average over tillage treatments, each increment in mulch rate brought about significant increase in grain yield over preceding mulch rates. Accordingly, 3 and 6 mg ha^{-1} tef straw mulch increased the sorghum grain yield in the order of 23.14 and 41.90% over control, respectively. Such yield increase due to mulch application is usual. Yield increases due to mulch application primarily attributed to greater water conservation in semi-arid regions was also experienced and many researchers emphasized about the link between crop residue management and tillage to increase yield of crops in semi-arid areas due to the enhanced stored water with mulch application [17, 18]. On the other hand, various results have been reported of enhanced stored water with the mulch application without being reflected to bring higher grain yield as the result of many reasons like poor seedling establishment at early growth stage and other factors for zero-tillage [19, 20]. Tied ridge yield was less with mulch applied, possibly due to excessive soil moisture during the growing season and transient water logging with mulch applied. Jones and Stewart [21] and Kilewe and Ulsaka [9] also observed problems of water logging with tied ridging following heavy rainstorms, thereby reducing the benefits of the tied ridge technique with mulch applied. Grain yield was 15 and 7% less with mulch levels of 3 and 6 mg ha^{-1}, respectively, as compared to no mulch with tied ridging.

Interaction effect revealed that mulch application at 3 mg ha^{-1} brought about significant increased in grain yield over control incase of conventional as well

Table 2: Effect of tillage and mulch rate interaction on grain yield (kg ha^{-1}) of sorghum at Melkassa in 2003

	*Tillage systems			
Mulch rate (mg ha^{-1})	CT	ZT	TR	Mean
0	2404	2156	4190	2916
3	4076	3141	3558	3591
6	4688	3867	3859	4138
Mean	3722	3054	3869	

	Tillage	Mulch	Tillage x ¶(a)	Mulch ¥(b)
Sem ±	197	161	279	301
LSD$_{0.05}$	ns	494	857	924
CV (%)			13.63	

¶LSD$_{(0.05)}$ for comparing two mulch levels treatment means within a tillage treatment

¥LSD$_{(0.05)}$ for comparing two tillage treatment means at the same or different mulch rates tillage treatment

*Conventional tillage (CT); Zero-tillage (ZT); Tied- ridging (TR)

zero-tilled plots (Table 2). Further more, 6 mg ha^{-1} mulch further increased yields significantly over control (no-mulch) under conventional as well as zero-tilled plots and yield increases were in the order of 95 and 79.35% over control, respectively. On the other hand, mulch application with tied ridging had no effect on grain yield/ha. Sorghum crop under control (no-mulch) with tied ridging produced comparable yield levels to highest grain yields obtained due to 6 mg ha^{-1} mulch under conventional tillage treatments. 6 mg ha^{-1} tef straw mulch under conventional tillage out yield all other treatments.

The lowest yield was experienced from zero-tillage plot, at all levels of mulch application. This result is in agreement with [20, 22], where zero-tillage has also been found to give lower yield, which are subject to restricted root growth. From existing literature, there is a considerable evidence existing for unlikely poor performance of the zero-tillage associated with the influence of climate, soil, management practices that zero-tillage performance in terms of enhancing yield could be limited, especially at the earlier few years where zero tillage persist. It was also clearly observed in many occasions that the zero-tillage did not increase yield when the precipitation reasonably ample or increased [23, 24]. Other studies have shown no, or variable difference in crop yield between zero-tillage and conventional tillage [25].

According to this study, highest sorghum grain yield (4688 kg ha^{-1}) was recorded due to conventional tillage. Results reported showed crop yields under conventional tillage as superior to those under conservation tillage like under semi-arid conditions in India [26]. There are, however, also many other results, which invalidate this and show the reverse, as it is evident from the extensive published data on tillage that affect crop yield, differs with soil conditions and environment [27 - 31].

There are ample evidence available substantiating the variable performance. It seems clear that the effect of zero-tillage or reduced tillage in particular on grain yield of many food crops could not be generated as long as relatively few long-term studies of zero-tillage have been in existence to generate reliable data from repeated measurement of important parameters and could be applied over a wide-scale for variable semi-arid areas of Ethiopia.

Stover yields: Stover yield was affected by mulch rate with a similar trend of response as with grain yield. An exception was with tied ridging where grain yield decreased with mulch rate, while stover yield increased (Table 3). Stover yield was not affected by tillage treatment at the desired level of probability. The interaction effect of tillage systems and mulch management was not significant on the mean stover yield of sorghum crops, however, the trend observed in response to this interaction was interesting.

Stover yield was not affected by the different tillage systems. Although increase in stover yields because of mulch rate with tillage was not significant, highest mean stover yield (10980 kg ha^{-1}) were recorded in the plots, which received mulch level of 6 mg ha^{-1} across different tillage systems but no significant differences in straw yields were recorded due to the two higher level of mulch rates (3 and 6 mg ha^{-1} mulch rates). This highlights the importance of mere coverage of soil surface with tef straw mulch (3 mg ha^{-1}) could be enough to reduce evaporation loss from the soil surface and to retain more moisture in the soil layer through enhanced infiltration [29, 32].

The result also indicated that aboveground biomass yield of the crop was only significantly affected by the main effect of mulch rate not by any of the other effect. Generally, aboveground biomass was also following the same trend of stover yield of the crop as most of the component was mainly attributed by the stover of the sorghum crop (Table 3).

It is inferred from the above discussion that in order to maximize the sorghum stover yield which is an important product for the farmers for various purposes, according to this study mulching using cereal straw mulch like tef straw at the rate of 3 mg ha^{-1} appears quiet adequate.

Harvest index: Although, harvest index was not affected by mulch rate, tillage and their interaction (Table 4),

Table 3: Main effects of tillage and mulch rate on stover and above ground biomass yield of sorghum at Melkassa in 2003

Treatments	Stover yield (kg ha^{-1})	Above ground biomass (kg ha^{-1})
*Tillage systems		
CT	9155	13259
ZT	8314	11394
TR	10340	14293
Sem ±	613	644
$LSD_{0.05}$	ns	ns
Mulch rate (mg ha^{-1})		
0	6311	9614
3	10518	14322
6	10980	14710
Sem ±	402	404
$LSD_{0.05}$	1235	1241
CV (%)	13.03	9.43

Table 4: Main effects of tillage and mulch rate on panicle weight per plant, 1000 grain weight and harvest index of sorghum at Melkassa in 2003

Treatments	Harvest index (%)
*Tillage systems	
CT	34.18
ZT	32.34
TR	39.24
Sem ±	3.16
$LSD_{0.05}$	ns
Mulch rate (mg ha^{-1})	
0	34.84
3	32.76
6	38.16
Sem ±	2.57
$LSD_{0.05}$	ns
CV (%)	21.86

ns - not significant

*Conventional tillage (CT); zero-tillage (ZT); Tied ridging (TR)

HI increased from 34 to 38% as the mulch rate was increased and was greatest with tied ridging (45%). Sow *et al.* [33] also reported highest HI value on the tied ridged plot.

Table 5: Main effect of tillage and mulch rates on total seasonal water use (mm) of sorghum at Melkassa (2003)

Treatments	Total seasonal water use (mm)
*Tillage systems	
CT	600.03
ZT	609.59
TR	618.07
Sem ±	4.80
$LSD_{0.05}$	ns
Mulch rate (mg ha^{-1})	
0	594.97
3	618.48
6	613.70
Sem ±	5.50
$LSD_{0.05}$	16.89
CV %	2.70

ns - not significant

*Conventional tillage (CT); Zero-tillage (ZT); Tied- ridging (TR)

Seasonal water use: Total rainfall amount from June to October (2004) was significantly above the long-term average rainfall received (Fig. 1). However, rainfall was below average early in the season June and October 2004 in the late cropping season and no rains occurred during October at all. Considerably above average rainfall during July and September and near average rainfall during August took place in 2004 (Fig. 1). Rainfall distribution was poor, particularly in late growth stage of the crop (October) with almost no rainfall and the crop was stressed during the late grain filling stage to affect the yield and soil water content in the soil profile. Much of the rains in July and August did not help the crops much, as some of the water lost as runoff in the heavy rainstorm. Evaporation loss was also recurrent in the area by the intermittent high intensity wind and strong evapotranspiration loss due to the periodic high temperature and the subsequent high solar radiation (Fig. 1).

The total seasonal water use differed significantly due to the main effect of mulch rates. The difference between the seasonal water use across the different tillage systems showed non-significant differences, tied ridging tended to recorded highest seasonal water use (618 mm) followed by zero-tillage (609 mm) and the least by the conventional tillage (600 mm).

It was found that water use was influenced statistically ($p \leq 0.05$) by the main effects of mulch rates and also by seasonal rainfall, since a higher amount of rainfall (587 mm) during the cropping season occurred (Fig. 1). Significantly higher seasonal water use was observed in mulched treatment as compared to no mulch treatment. As evident from the data in (Table 5), the significantly greater seasonal water use had been observed with increase in mulch rate from no mulch application to 3 mg ha^{-1}, which was the maximum. Seasonal water use was comparable at the highest mulch rate (6 mg ha^{-1}) as compared to the lower mulch rate (3 mg ha^{-1}). Similar result was also reported by Lal [34] in Nigeria and he observed he effect of mulch is more visible after few years.

Grain and stover water use efficiency: Water use efficiency (WUE) as affected by tillage and mulch levels and their interaction, generally followed similar pattern for grain, stover and total dry matter yields (Table 6 and 7). Statistically significant WUE values for grain production were observed by mulch rates and the interaction due to mulch and tillage. The WUE for both stover yield and total dry matter were significantly ($p \leq 0.01$) influenced by

Table 6: Effect of tillage and mulch rates interaction on grain water use efficiency (kg ha^{-1} mm^{-1}) of sorghum at Melkassa in 2003

Mulch rates (mg ha^{-1})	*Tillage systems CT	ZT	TR	Mean
0	4.15	3.69	6.72	4.85
3	6.49	5.08	5.62	5.73
6	7.44	6.09	6.12	6.55
Mean	6.02	4.95	6.15	
	Tillage	Mulch	Tillage x Mulch ¶(a)	¥(b)
Sem ±	0.25	0.24	0.42	0.43
LSD$_{0.05}$	ns	0.73	1.29	1.32
CV (%)				13.01

¶LSD$_{(0.05)}$ for comparing two mulch levels treatment means within a tillage treatment

¥LSD$_{(0.05)}$ for comparing two tillage treatment means at the same or different mulch rates

*Conventional tillage (CT); Zero-tillage (ZT); Tie ridging (TR)

Table 7: Main effects of tillage and mulch rates on water use efficiency (WUE) in (kg ha^{-1} mm^{-1}) for stover and total dry matter production in 2003 at Melkassa

Treatments	WUE for stover yield	WUE for total dry matter
*Tillage systems		
CT	15.12	15.15
ZT	13.57	13.59
TR	16.72	16.75
Sem ±	0.94	0.94
LSD$_{0.05}$	ns	ns
Mulch rate (mg ha^{-1})		
0	10.53	10.55
3	16.98	17.00
6	17.90	17.90
Sem ±	0.94	0.94
LSD$_{0.05}$	2.88	2.88
CV (%)	13.12	13.12

ns - non significant

Conventional tillage (ZT); Zero-tillage (ZT); Tied ridging (TR)

the main effect of mulch rate applied only. Average WUE values for grain production increased from 4.9 kg ha^{-1} mm^{-1} due to zero-tillage to 6.15 kg ha^{-1} mm^{-1} due to tied ridging. Increased WUE was observed as the mulch rate increased from no mulch application to the highest level of mulch application (6 mg ha^{-1}), from 4.85 kg ha^{-1} mm^{-1} to 6.55 kg ha^{-1} mm^{-1} of water used, respectively.

Any practice that improves soil water conservation in that soil layer reflected in the total crop water use and grain yield but the WUE quite differed, how ever there are many reasons for the resulting differences in WUE and as it was evident from (Table 6) that WUE was decreased due to higher utilization of water in the zero-tillage treatments, possibly because of relatively higher rainfall year as compared to lesser rainfall years when the water supply is limited and transpiration (T) might be increased relative to other pathways of loss. Finally if the total water supply is increased, WUE will only be increased if T is increased proportionally [20, 22, 35 - 37] or it could be due to some undesirable factors imposed on zero-tillage which is liable to yield reduction especially at first few years as reported by many workers [20, 22].

The different responses in WUE for grain production due to main effects of tillage and mulch and their interaction suggested that some additional growth occurred on the tied ridged plots and the conventional plots as progressively the mulch application was raised to the higher level. Additional higher precipitation accompanied with greater water conservation level due to mulching during critical grain filling stages might have improved grain yields. Consequently, these treatments resulted in greater WUE values. Cooper *et al.* [38] also reported that reduction of evaporation (E) by conservation tillage could not be possible in dryland environments because of poor ground cover by the crop especially during early stage of the crop. Gibson *et al.* [39] also reported the reduction in WUE associated with lesser evapotranspiration (seasonal water use) during cropping season of the crop as the result of lower soil water storage at early growth stage. How ever, several research results from the long-term field experiment demonstrated the advantage of zero-tillage and straw mulch management from improved grain yields and greater water use efficiency in regions receiving annual precipitation of more than 250 mm [40]. As it was clearly observed in present study and other areas of semi-aid areas, the zero-tillage did not increase yield and water use efficiency when the precipitation reasonably ample or increased [23].

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