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Conservation Tillage and Crop Rotation: Concomitant Systems to Incorporate Tef [*Eragrostis tef* (Zucc.) Trotter] Production with Sustainability in the Dryland Oromia

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ABSTRACT

The encorpration of tef production with sustainability in field experiments was conducted in 2003 and 2004 at two locations using different tillage options as the main plot and two cropping systems as sub plots under a randomized complete block design with three replications. Significantly higher mean grain yield of 1231 kg/ha was obtained from rotation plots as compared to the grain yield obtained from continuous tef monoculture (851 kg/ha). The same trend as grain yield was observed for straw and aboveground biomass yields. The increment of soil organic matter content for no-tillage over conventional tillage were 0.30 and 0.28% at 0-15 cm and 15-30 cm soil depths, respectively. Total soil nitrogen was increased by 0.03% in no-tillage over conventional tillage. The bulk density of no tillage at 0-15 cm (1.16 g cm^{-3}) and 15-30 cm (1.20 g cm^{-3}) was remarkably higher than that of conventional tillage (1.09 g cm^{-3} and 1.10 g cm^{-3}, respectively). Both soil organic matter and total soil nitrogen concentrations were higher for rotational cropping than monoculture. In the dryland Oromia, increasing soil organic matter is especially important, since many soils are naturally low in organic matter and high temperature leads to its rapid breakdown. Hence, the implementation of conservation tillage and crop rotation can be an effective concomitant strategy in improving soil properties and increasing yield of tef without an adverse impact on the environment.

Key words: Concomitant, conservation tillage, monoculture, rotation, sustainable

INTRODUCTION

Tillage systems play a significant role in agricultural production throughout the dryland, central rift valley of Oromia, Ethiopia. The central rift valley of Oromia is mainly under rainfed crop production, and composed of low resource farmers. The region is also characterized by frequent drought, inherently low soil fertility, low organic matter and poorly distributed rainfall patterns. Due to increasing pressure on the land for more reliable crop production, previously considered low agricultural potential areas are under intensive tillage practices. Unfortunately, increased tillage can reduce soil organic matter, which is a natural reservoir for nutrients, buffers against soil erosion, and overall improvement of the soil environment to sustain soil productivity

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(Al-Kaisi and Hanna, 2002). Maintaining soil productivity requires an agriculture management system that maintains or improves soil organic matter content. Continuous tef monoculture is also the most dominant crop production system in the area. However, the results obtained in the dryland and sub-humid areas of the country indicated that yield reduction due to monoculture was the big problem (Worku, 2002; Tesfa *et al*., 2003). Furthermore, an ever-increasing rate in the price of inorganic fertlizer is continously becoming a challenge for crop production in the areas and these encourage the use of alternative sources of fertilizer. Alternating the choice of crops in the cropping systems as one of the approaches may help in solving such problems associated with monoculture. Crop rotations have many benefits that can influence the success of crop production enterprises both under conventional tillage and conservation tillage systems. Experiments conducted in the central rift valley of Oromia showed an increased grain yield of cereal by rotating it after haricot bean (Lemma *et al*.,1994). Unfortunately, these results were not substantiated with data on soil nutrient changes. Combining cropping systems and conservation tillage practices, such as no-tillage are proven to be very effective in improving soil organic matter and yield of crops in many countries (Al-Kaisi and Hanna, 2002). Conservation tillage benefits include less soil erosion, less water pollution, increased organic matter in the soil, lower labor costs, less time required per crop, and in some cases the possibility of an additional crop yield per year (Okoba *et al*., 1997). The investigation so far conducted in Oromia mainly concentrated on the importance of conservation tillage on grain yield of cereal in the sub-humid high rainfall areas. Almost no research with no supportive data on soil properties has been carried out in the dryland with less and poorly distributed rainfall. Cognizant to these facts, the present study was conducted with the objective to identify the appropriate tillage and cropping system for sustainable tef production.

MATERIALS AND METHODS

Site characteristics: Field studies were conducted in 2003 and 2004 at Malkassa Agricultural Research Center (MARC) and Wolenchity research sub station, both found in the central rift valley of Oromia, Eastern Shoa zone, representing the rain fed dryland agro-climatic conditions but differing mainly in the amount of annual precipitation and soil types. The Malkassa Agricultural Research Center (MARC), at an altitude of 1550 m, is located on latitude 8°24’N and longitude 39°12’E. The soil surface at the experimental site is loam in texture and contains 44, 36, and 20% sand, silt and clay, respectively with a medium soil pH (6.56). The Wolenchity Agricultural Research sub station is located at 8° 40’N latitude and 39 ° 26’E longit, at 1480 m above sea level. Soil test values at Wolenchity at the onset of the study indicated a well-drained sandy loam soil (46% sand, 34% silt, and 20% clay) with a medium soil pH (6.64).

The experimental site at both locations had been in a continuous tef production before 2000. Since 2000 the adjacent sites of fixed plots for tef were maintained at both locations in a continuous 3-year (2000 to 2002) monoculture system and a researcher had managed the fields under different tillage options before the initiation of the present study. In year 2002, the fixed plots for each tillage treatment of 8 m long and 6.75 m wide at Wolenchity and 8 m wide and 10 m long at Malkassa, were divided into two equal areas. In one side of the previous tef plot, haricot bean as a precursor crop at both locations were grown while on the adjacent remaining equal areas of the same plot tef monoculture continued. In 2003, tef was grown on the previously haricot bean plots to examine the effect of precursor crops on the succeeding crop. The remaining equal areas of the same plot were continued with tef monoculture to observe the effect of monoculture on the test crop. The same experiment and procedures were repeated in 2004.

Tillage treatments: Three options of conservation tillage system as pre-plant no-tillage with pre and post emergence herbicides and supplemental hand weeding (T1), pre-plant no-tillage with pre and post emergence herbicide but no hand weeding (T2), pre-plant no-tillage with only pre emergence herbicide and supplemental hand weeding (T3), two options of conventional tillage system as four times plowing and post-emergence herbicide (T4), and four times plowing and two times hand weeding (T5) were compared. In all options of conservation tillage systems, no soil disturbances were made except for seeding and fertilizer application. Two herbicides, glyphosate [N-(phosphonomethyl) glycine] at a rate of 3 l ha^{-1} and 2, 4-D at a rate of 1 l ha^{-1} were applied 10 days before planting and a month after planting, respectively. The conventional tillage plot was plowed with traditional oxen plow 'Maresha' following the experiences of the surrounding farmers. In conventional tillage the first hand weeding was 20-29 days after crop emergence (DAE) and second hand weeding 40-50 DAE. Combination of the treatments and their descriptions are provided in Table 1.

Experimental design: The five tillage treatments were assigned as main plots and the two cropping systems as sub-plots and evaluated in a spilt plot design with three replications. Plot size for each tillage treatment was 8 m long and 6.75 m wide at Wolenchity and 8 m wide and 10 m long at Malkassa.

Cultural practices: *DZ-cross-37* tef variety was hand broadcasted in all plots in both years. Forty Kg N/ha and 60 Kg P_2O_5/ha were applied for tef varieties with the entire P_2O_5 and half of N at planting and the other half of N as a split application at tillering stage.

Data collection:

Soil parameter: Soil samples were taken from each plot, air-dried, ground and passed through a 2 mm sieve and preserved for soil analyses. The soil properties were evaluated by measuring bulk density, soil moisture, total nitrogen, available P and K, and soil organic matter concentrations by following the method developed by AOAC (1960). Soil moisture at 0-15 and 15-30 cm depth was determined gravimetrically for each plot in the central row in two replications and expressed on weight basis. Soil pH was measured in the supernatant suspension of a 1:2.5 soil: water mixture by using a pH meter (model HI8521). Total nitrogen (N), available phosphorus (P), and exchangeable potassium (K) were determined by using the semi-micro Kjeldahl digestion method (Bremner and Mulvancy, 1982), Olsen method using Spectrometer (Olsen and Sommers, 1982), and Morgan Extraction method using Flame photometer (model CL 378 ELICO), respectively. Organic Carbon was determined according to Walkley-Black method (Jackson, 1958).

Biological yields: The grain and straw yields of the crop were determined by hand harvesting all plants from 7 m long by 3 m wide at Wolenchity and 9 m long by 3 m wide at Malkassa.

Statistical analysis: Data were analyzed using the SAS software statistical package (SAS,

Table 1 Treatment combinations of five tillage systems during the study period.

Treatment	Tillage systems	Treatment combinations[a]
T1	Conservation Tillage	No-tillage (3.0 l ha^{-1} glyphosate + 1.0 l ha^{-1} 2, 4-D+1 time HW)
T2	Conservation Tillage	No-tillage (3.0 l ha^{-1} glyphosate + 1.0 l ha^{-1} 2, 4-D)
T3	Conservation Tillage	No-tillage (3.0 l ha^{-1} glyphosate + 1 time HW)
T4	Conventional Tillage	Tilled (four times plowing + 1.0 l ha^{-1} 2, 4-D + 1 time HW)
T5	Conventional Tillage	Tilled (four times plowing + two times HW)

[a]Glyphosate = N-(phosphonomethyl)glycine; 2,4-D = (2,4-dichlorophenoxy) acetic acid; HW = hand weeding

1989) and Duncan's multiple range tests were used to examine differences between treatment means.

RESULT AND DISCUSSION

Grain yield, straw and aboveground biomass:

The present study showed that for the average of the two locations there were highly significant (p<0.01) differences in mean grain yield between the two cropping systems (Table 2), and significantly higher mean grain yield of 1231 kg ha^{-1} was obtained from rotation plots as compared to the grain yield obtained from continuous tef monoculture (851 kg ha^{-1}). The increase in grain yield of the succeeding cereal crop was believed to be due to the contribution of preceding legume crop which improved the soil fertility through atmospheric N-fixation (Kumar Rao *et al.*, 1983). An increase cereal grain yield was obtained in India by a previous legume crop (Ahlawat *et al.*, 1981). Results of the experiment conducted in the central rift valley of Ethiopia showed an increased grain yield by rotating it after haricot bean (Lemma *et al.*,1994). The mean grain yield between the two locations (1068.58 kg ha^{-1} at Wolenchity and 1012.84 kg ha^{-1} at Malkassa) was similar. The differences in grain yield among tillage systems and the interaction of tillage to cropping system were not significant at 5% level of significance.

Highly significant differences (P<0.01) in mean straw and aboveground biomass yields were observed between the two cropping system (Table 3 and 4). Like grain yield the mean straw (Table 3) and above ground biomass yield (Table 4) obtained from rotation plots were significantly higher than that obtained from continuous monoculture plots. Results of several

Table 2 The influence of cropping and tillage system on tef grain yield (kg ha^{-1}) in 2004.

Tillage system[2]	Cropping system[1]		
	Rotation	Monoculture	Mean
NT+Gly+2, 4 D+HW	1225.96	1004.81	1115.38 a
NT+Gly+2, 4 D	1048.98	922.40	985.69 a
NT+Gly+HW	1325.59	758.87	1042.23 a
T+2, 4 D+HW	1322.63	733.95	1028.29 a
T+2HW (Conventional tillage)	1231.33	832.56	1031.95 a
Mean	1230.90 a	850.52 b	

[1] means followed by the same letter are not significantly different at 5 % probability level of significance. [2] NT = No-tillage, Gly = Glyphosate, HW = Hand weeding, T = Tillage

Table 3 The influence of cropping and tillage system on tef straw yield (kg ha^{-1}) in 2004.

Tillage system	Cropping system[1]		
	Rotation	Monoculture	Mean
NT+Gly+2, 4 D+HW	2438.07	1920.02	2179 a
NT+Gly+2, 4 D	2277.99	2283.69	2281 a
NT+Gly+HW	2723.59	1925.14	2324 a
T+2, 4 D+HW	3022.27	1591.27	2307 a
T+2HW (Conventional tillage)	2707.43	1795.76	2252 a
Mean	2633.87 a	1903.18 b	
CV 27.46			

[1] means followed by the same letter are not significantly different at 5% probability level of significance. [2] NT = No-tillage, Gly = Glyphosate, HW = Hand weeding, T = Tillage.

experiments in the other countries also provide evidence of an increased productivity of subsequent non-legume crops. Many reports showed that yields of cereal crops were usually higher when the crop was rotated with some other crop rather than grown continiously (Giri ans De, 1979; Baldock *et al*., 1981; Lemma *et al*., 1994). A yield increase of maize by 57% and total plant dry matter by 32% following pigeonpea was also reported (Kumar Rao *et al*., 1983). Unlike grain yield, significantly higher straw and biomass yield were obtained at Malkassa (2721 kg ha^{-1}, 3734 kg ha^{-1}, respectively) than that obtained at Wolenchity (1816 kg ha^{-1}, 2885 kg ha^{-1}, respectively).

Harvest Index (HI):

HI was highly significant (P<0.01) by location, and by the interaction between location and cropping system (Table 5). Harvest index at Wolenchity was significantly higher than at Malkassa. HI varied with the cropping system of the two locations and significantly higher HI obtained from monoculture of Wolenchity than that obtained from rotational plot of the same location which in turn significantly higher than the HI obtained from either of the cropping systems at Malkassa. But there was no significant variation between the two cropping systems at Malkassa. Although harvest index is an easy measurement, it is not a reliable indicator of yield and should not be used without at least an understanding of the development of yield (Seetharama and Soman, 1990).

Tillage and cropping system on some soil properties

The impact of tillage and cropping system on some soil chemical properties at Malkassa is presented in Table (6). The amount of soil organic matter (SOM) and total soil nitrogen (TSN) increased after five years in both tillage systems. The soil organic matter content increased significantly near the soil surface (0-15 cm) in no tillage. Increases in soil organic matter for no-tillage over conventional tillage were 0.30 and 0.28% at 0-15 cm and 15-30 cm soil profile depths, respectively. For total soil nitrogen increases in no-tillage were 0.03% at each of two depths over conventional tillage. Available P results were variable but differences could not be attributed to tillage. Exchangeable potassium was generally

Table 5 Influence of location and cropping system on HI.

Cropping system	Location	
	Wolenchity	Malkassa
Rotation	0.358 B	0.291 C
Continuous	0.401 A	0.254 C
Mean	0.379	0.272
Cv 15.36		

[1] means followed by the same letter are not significantly different at 5% probability level of significance.

Table 4 Influence of cropping and tillage systems on biomass yield of tef (kg ha^{-1}).

Tillage system	Cropping system[1]		
	Rotation	Monoculture	Mean
NT+Gly+2, 4 D+HW	3664.03	2924.83	3294.43 a
NT+Gly+2, 4 D	3326.98	3206.09	3266.53 a
NT+Gly+HW	4049.18	2684.01	3366.60 a
T+2, 4 D+HW	4344.91	2325.22	3335.06 a
T+2HW (Conventional tillage)	3938.76	2628.33	3283.54 a
Mean	3864.77 a	2753.70 b	
Cv 24.19			

[1] means followed by the same letter are not significantly different at 5% probability level of significance. [2] NT = No-tillage, Gly = Glyphosate, HW = Hand weeding, T = Tillage.

very high for all tillage systems and cropping systems. Soil depth and tillage type did not have much effect on soil pH and EC. Soil organic matter and total soil nitrogen remarkably increased in rotation plot as compared to continuous monoculture plot within the same tillage system (Table 6). The impact of cropping system was greatly observed in conventional tillage compared with the corresponding no tillage. This might be that no tillage had the ability to increase soil nutrients equally for continuous and rotation crops. The continuous tef monoculture had the lowest SOM and TSN concentrations under conventional tillage.

The C/N ratio of whole soil (C/N = 15.5) was impacted by tillage and cropping system. The average C/N ratio of the no tillage (C/N = 12.75) was significantly lower than the average ratios of the conventional tillage (C/N = 18.32). The C/N ratio for the average of two tillage systems was lower under rotation (C/N = 14.365) than under continuous cropping (C/N = 16.71). However, the lowest C/N ratio (11.88) and the highest C/N ratio (21.53) were found for continuous cropping under no-tillage and conventional tillage, respectively. The higher the C/N ratio for the conventional tillage implies less N nutrients in the soil.

Bulk density for continuous tef monoculture was found under desirable category at both 0–15 and 15–30 cm soil depths (Table 6) and was impacted by tillage system. Bulk density increased with depth, ranging from 1.09 g cm$^{?3}$ at 0–15 cm to 1.2 g cm$^{?3}$ at 15–30 cm. The bulk densities of no tillage at 0-15 cm (1.16 g cm$^{?3}$) and 15-30 cm (1.20 g cm$^{?3}$) were significantly higher than that of conventional tillage for both soil depths (1.09 g cm$^{?3}$) and (1.10 g cm$^{?3}$), respectively. However, there was no indication of compaction as there was low bulk density for both tillage systems. This might be attributed to low effect of animal traction to compact soil. After harvesting, it was found that at both soil depths the moisture content of both tillage systems was the same.

The effect of tillage and cropping system on some soil chemical properties at Wolenchity is given in Table 7. Soil depth, tillage type and cropping system had only a slight effect on soil total nitrogen, available phosphorus and pH at Wolenchity. Total N was similar for each tillage type and each cropping system except possibly more soil N at the 0-30 cm depth in the rotational plot under conventional tillage than under other tillage practices.

Available P was generally higher for no tillage and less at greater depth for rotational plot of both tillage systems, this could be due to the

Table 6 Effect of tillage and cropping system on soil properties at different soil depths (0-15 cm and 15-30 cm) at Malkassa.

Soil property	No tillage				Conventional tillage			
	Rotation		Monoculture		Rotation		Monoculture	
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
OC (%)	0.90	0.90	0.90	0.67	0.80	0.77	0.74	0.56
TN (%)	0.07	0.07	0.07	0.07	0.05	0.05	0.03	0.03
Av P (ppm)	13.23	11.90	6.66	8.94	9.12	10.81	19.70	11.49
Av K (meq/100gm)	481.28	409.60	363.88	363.88	471.50	391.02	426.21	497.70
PH (1:2.5)	6.33	6.43	6.33	6.39	6.41	6.40	6.55	6.34
EC (1:2.5)	0.11	0.09	0.08	0.07	0.09	0.13	0.11	0.08
OM (%)	2.05	2.05	2.05	1.53	1.83	1.76	1.68	1.27
BD (g cm^{-3})			1.16	1.20			1.09	1.10
Moisture (%, w/w)			7.42	13.26			6.68	13.63

relatively immobile nature in the soil and so it remained concentrated more near the site of application on the top of the soil. But available P results were variable for continuous cropping in which a significantly lower value was obtained in conventional tillage at a greater soil depth (30 cm) while no remarkable difference was observed for no tillage.

Soil organic matter was greatly reduced with increment of depth for all tillage systems and cropping systems. An increase in organic matter gradient generally occurred under no-tillage, with most of the organic matter concentrationed at the surface and it decreased with depth. However, organic matter was evenly distributed throughout the ploughed layer in conventionally tilled plots. It has been shown in various studies that no-tillage can increase soil organic matter (Al-Kaisi and Hanna, 2002). With 8 years of experiments, increased soil organic matter and nitrogen storage were observed at 0–5 cm soil depth in no tillage (Ortega *et al*., 2002). No-tillage is considered the most effective conservation system for improving soil organic matter due to no soil disturbance (Triplet, 1986). This characteristic of no-tillage was extremely beneficial because surface residue and soil organic matter were left undisturbed, slowing decomposition and maximizing soil organic matter gains. In addition to increased water holding capacity, soil organic matter helped create soil conditions that improved water infiltration and reduced surface runoff. Overall, soil organic matter was a necessary component for improving soil and water quality. It has been well documented that increased tillage intensities can reduce soil organic matter in the topsoil due to increased microbial activity and carbon oxidation (Al-Kaisi and Hanna, 2002).

CONCLUSION

Significantly higher mean grain yield was obtained from rotation plots as compared to that obtained from continuous tef monoculture. The same trend as grain yield was observed for straw and above ground biomass yields. Soil organic matter and total soil nitrogen storage were increased by no tillage in surface soils. Crop rotation increased soil organic matter and total nitrogen compared to the tef monoculture system. Generally, conservation tillage systems varied in their level of impact on soil chemical properties depending on the type of tillage system, type of cropping system, and location. In conclusion, the implementation of conservation tillage and crop rotation can be an effective concomitant strategy

Table 7 Impact of tillage and cropping system on soil chemical properties at different soil depths (0-15 cm and 15-30 cm) at Wolenchity.

Tillage system	Depth (cm)	TN (%)	Av. P (ppm)	pH (1:2.5)	EC (1:2.5)	OM (%)
Tef continuous monoculture						
No tillage	0-15	0.13	11.18	8.09	0.08	1.70
	15-30	0.11	11.84	8.26	0.19	1.45
Conventional tillage	0-15	0.12	11.20	8.16	0.09	1.68
	15-30	0.13	7.36	8.29	0.19	1.42
Tef rotation (after haricot bean)						
No tillage	0-15	0.12	12.40	8.09	0.10	1.72
	15-30	0.12	12.00	8.19	0.20	1.39
Conventional tillage	0-15	0.12	9.04	7.98	0.09	1.66
	15-30	0.14	7.68	8.12	0.21	1.43

in improving soil properties and increasing yield of tef without adversely impacting the environment.

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