Short-term effects of conservation tillage on soil (Vertisol) and crop (teff, *Eragrostis tef*) attributes in the northern Ethiopian highlands

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Abstract
A conservation agriculture (CA) experiment was conducted in 2006 at Adigudom, Tigray, Northern Ethiopia, on experimental plots established in 2005 on a farmer's field. The objectives of this experiment were to evaluate the short term changes in soil quality of a Vertisol due to the implementation of conservation agriculture practices and to assess their effect on runoff and soil loss (not reported here), crop yield and yield components of teff (*Eragrostis tef* (Zucc.) Trotter). The treatments were permanent bed (PB), *terwah* (TERW) and conventional tillage (TRAD). Soil organic matter (SOM) was significantly higher in PB (2.49 %) compared to TRAD (2.33 %) and TERW (2.36 %). Although aggregate stability of PB (0.94) was higher than TRAD (0.83), the difference was not significant. PB had larger macroporosity (0.07) compared to the other treatments. The other soil physical quality parameters analysed showed, however, inconsistency between treatments. Moreover the plant available water content of all treatments was similar. Despite the above soil physical properties improvements, which most probably resulted in higher soil water storage in PB than in the other treatments, yield, biomass and plant height of teff were significantly higher in TRAD than PB. The significantly high weed dry matter at first weeding in PB, the types of weeds and their water uptake behaviour may have caused the reduced teff yield. Herbicides must be used while growing teff in CA experiments.

Key Words
Conservation agriculture, permanent bed, aggregate stability, runoff, soil loss, teff.

Introduction
Agriculture in Ethiopia is dominated by rainfed farming of low productivity. Tigray, the northern-most region of the country, suffers from extreme land degradation as steep slopes have been cultivated for many centuries and are subject to serious soil erosion (Wolde *et al.* 2007). Rainfall is seasonal and erratic in Northern Ethiopia, particularly in Tigray. Consequently, there is strong seasonal (~8 months) moisture stress limiting the productivity of rainfed agriculture in the region (Haregeweyn *et al.* 2005). The conventional tillage that uses *maresha* as primary tillage, followed by repeated secondary shallow tillage, is aimed at control of weeds, moisture conservation and increased soil warming (Melesse *et al.* 2008).
In the study area, particularly since the widespread introduction of stone bunds in the late 1980s, ploughing is done parallel to the contour. The first furrow is made at the lower end of the field, and the oxen move upslope for each subsequent furrow. Around the central rift valley area of Ethiopia, however, the directions of any two consecutive tillage operations is usually perpendicular to each other in order to reach the untilled strip of land (Melesse *et al.* 2008). But these repeated operations, aimed to remove weeds and prevent crust formation, cause moist soil to move to the surface which favours loss of water by evaporation, exposes the soil to both wind and water erosion and causes structural damage (Melesse *et al.* 2008). Such detrimental effects can be improved to some extent by other management options like conservation agriculture (CA) practices, including permanent beds and semi-permanent beds.
Gebreegziabher *et al.* (2009) studied the effect of conservation tillage practices on the Adigudom Vertisol using wheat as an indicator crop. However, it is important to study how the treatments respond for teff. Tef is an endemic and major staple crop in Ethiopia. Traditionally, it is cultivated with intensive seed bed preparations with 3-5 passes in the semi-arid and 5-8 passes in the humid areas of the country with the ox driven local *maresha* aimed mainly to remove weeds. Due to the dominance of the vertic soils in the area, tillage is very difficult and farmers associate this with injuries on the shoulders of the oxen. More labour

input is needed and longer time to accomplish the ploughing activity. In contradiction to the traditional belief, reduced tillage in experiments conducted in the central highland Vertisols with high rainfall have shown higher yield although, it was not statistically significant (Balesh *et al.* 2008). A similar study in the Adigudom Vertisol also showed promising results for the use of minimum tillage for teff growth (Habtegebrial *et al.* 2007). However, most of these studies stress only crop parameters and the gross margin of teff. There is little information on the effect of tillage practices on soil physical quality. Therefore, the objective of this study is to evaluate the impacts of CA practice, permanent beds together with the traditional practice like *terwah* and traditional tillage, on changes in some soil physical quality indicators, teff yield and its yield components. Results on the effect of these practices on runoff and soil loss are reported elsewhere in this publication (Araya *et al.* 2010).*

Material and methods

Study site

The CA experiment begun in January 2005 in Adigudom, Northern Ethiopia (13°14' N and 39°32' E) located ~740 km north of Addis Ababa at an altitude of 1960 m a.s.l.. The area has a cool tropical semi-arid climate, characterized by recurrent drought induced by moisture stress. Rainfall in the study site is unimodal, with > 85% falling in the period of July -September. The mean annual rainfall (26 yr) is 504.6 mm and the mean annual temperature is 23 °C. The average annual evapotranspiration was estimated as 1539 mm. According to USDA soil classification, the soil has a clay content of 73% and 24% silt content with high calcium content (20%) and high pH_{H2O} (8.1). Together with the swelling and shrinking characteristic which is observed from very wide and deep cracks during the dry season, the soil is classified as Calcic Vertisol according to the FAO-UNESCO classification, pelli Calcic Vertisol according to WRB and Typic Calciustert according to Soil Survey Staff.

Experimental layout

The experiment was conducted on a farmer's field under rainfed conditions. All ploughing and reshaping of the furrows was done using *maresha* (as described by Gebreegziabher *et al.* 2009). Tef was sown by broadcasting in all plots on August 4, 2006. The sowing rate was 30 kg/ha and the fertilizer rate was 100 kg/ha DAP and 50 kg/ha Urea for all treatments. The moisture content at sowing was 0.291 kg/kg. The experimental design was a randomized complete block with two replications for each of the following treatments:

1. Traditional tillage practice (TRAD): The land was ploughed three times, once in May, once in July and the last time before sowing on the sowing date.
2. *Terwah* (TERW): This is a traditional water conservation technique in which furrows are made with *maresha* along the contour at an interval of 1.5-2 m. It is similar to TRAD except for the furrows at regular interval and is repeated yearly.
3. Permanent beds (PB): Beds and furrows of 60-70 cm width (middle of the furrow to the next one) were made after ploughing the plots. The furrows were reshaped after every cropping season without any disturbance on the top of the bed. In the current experiment, the furrows were reshaped in May and refreshed on the sowing date.

The whole experimental field was isolated from the upslope area by a 1.2 m wide and 0.5 m deep ditch to avoid any flow of water entering the upper side of the experimental field. The plots were separated from each other by a 0.5 m wide ditch, in order to avoid surface or subsurface hydrological 'contact' between them. The size of each plot was 19 x 5 m and they had a 3% slope. Wheat was sown in the summer 2005 rainy season and teff in the rainy season of 2006. Runoff collection ditches at the bottom of each plot collected runoff and sediment generated from the experimental plots (see Araya *et al.* 2010).

Soil sampling and analysis

Disturbed composite samples of 1.5 kg were collected from each plot from 0-20 cm in May 2006, before first ploughing for analysis of soil texture, soil organic matter (SOM), $CaCO_3$, soil shrinkage characteristic curve and aggregate stability. Undisturbed soil samples were collected from each plot at the same time from the same depth to determine the soil water retention curve (SWRC). Standard sharpened steel 100 cm^3 cylinders were driven into the soil using a dedicated ring holder. All soil properties were determined using standard procedures. From the soil water retention curve, we derived macroporosity (MacPOR), matrix porosity (MatPOR), soil air capacity (AC), plant available water capacity (PAWC) and Dexter's (2004) soil physical quality index S. Macroporosity was deduced from the water content at a matric potential of -6 kPa, corresponding to pores with a diameter >50 µm. For more details about the soil analysis, we refer to Oicha *et* *al.* (2010). We further collected agronomic parameters including plant height at maturity, teff dry matter, yield, and weed dry matter. For the determination of yield, harvestable areas of 2 x 8 m and 2 x 6 m were delineated. Hand weeding was performed 4 and 8 weeks after sowing. The weed dry matter was determined by air-drying the first weeding. The Harvest Index was also calculated as the ratio of grain yield to the dry above-ground biomass.

Results

Soil organic matter and aggregate stability

PB had significantly higher (p=0.0003) soil organic matter (SOM) than TRAD and TERW, while the later two do not have a significant difference (Figure 1). Although the stability index of aggregates in PB was higher than for the TERW and TRAD (Figure 1), the differences among the three treatments were not significant. There was also no significant difference among the different size classes for the three treatments too (data not shown).

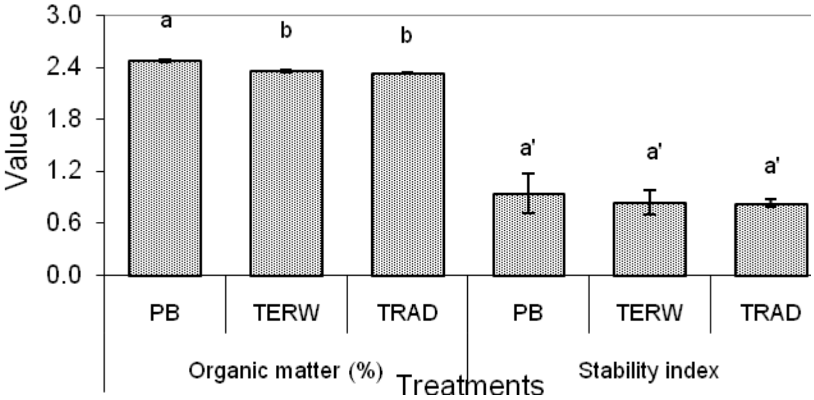

Figure 1. Soil organic matter and aggregate stability index for the three treatments for 0-20 cm soil depth

Soil water characteristic curve and derived soil physical quality parameters

Table 1 shows bulk density and soil moisture content at saturation (θ_s), S, MatPOR, MacPOR, θ_{PWP}, AC and PAWC values as calculated for the different treatments. PB and TRAD have relatively higher moisture content near saturation compared to TERW. The field-derived water content at field capacity was 0.510 m^3/m^3 for the site. This corresponds to matric potential values between -100 to -200 kPa, when using the SWRC (figure not shown). The bulk density and void ratio at oven dryness was 1.87 Mg/m^3 and 0.39, respectively (not shown). PB had higher MacPOR (0.070 m^3/m^3) compared to TRAD (0.063 m^3/m^3), while TERW (0.055 m^3/m^3) had the lowest value (Table 1). TRAD showed higher MatPOR followed by PB, whereas TERW had the lowest value. PB and TRAD had equivalent AC values, 0.087 m^3/m^3 and 0.088 m^3/m^3, respectively, which are higher than that of TERW (0.059 m^3/m^3). The θ_{PWP} of all the treatments is similar (~0.35 m^3/m^3). The PAWC of TERW (0.158 m^3/m^3) and TRAD (0.159 m^3/m^3) were slightly higher than PB (0.155 m^3/m^3).

Table 1. Bulk density and soil moisture at saturation calculated from SSCC, and soil physical quality index (S), matric porosity (MatPOR), macro porosity (MacPOR), water content at permanent wilting point (θ_{PWP}), plant available water content (PAWC) and air capacity (AC) calculated based on the van Genuchten (1980) parameters of the soil water retention curve for the different treatments. Values after ± are standard errors, α=0.05, n=6. Different letters indicate significant difference at p=0.05.

Treatments	Soil physical quality parameters							
	BD (Mg/m^3)	θ_s (m^3/m^3)	S	MatPOR (m^3/m^3)	MacPOR (m^3/m^3)	θ_{PWP} (m^3/m^3)	PAWC (m^3/m^3)	AC (m^3/m^3)
PB	0.98±0.031a	0.596±0.014a	0.067	0.527	0.070	0.355	0.155	0.087
TERW	1.05±0.004a	0.569±0.017a	0.060	0.514	0.055	0.352	0.158	0.059
TRAD	0.98±0.021a	0.598±0.009a	0.060	0.535	0.063	0.351	0.159	0.088

Crop yield and its components

PB resulted in the lowest grain yield, with a mean of 678 kg/ha (Table 2). There was also a significant difference in yield between TERW (mean yield of 925 kg/ha) and PB. There was significant difference

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(p=0.0016) among treatments in weed infestation. The mean mass of weed dry matter during the first weeding in the TRAD, TERW and PB was 77, 125 and 242 kg/ha, respectively. There was a significant (p<0.0001) negative correlation (r=-0.956, n=6) between weed dry matter and teff yield. Plant height at maturity was significantly higher for TRAD compared with both TERW and PB. The Harvest Index (HI) of PB and TERW was significantly (p=0.01) higher than TRAD (Table 2). Although there was a significant difference in yield between treatments, no difference in teff biomass was observed between PB and TERW.

Table 2. Teff yield, biomass, plant height, weed dry matter at first weeding and harvest index for the different treatments. Values between parentheses are standard deviation. Different letters indicate significant difference at p=0.05.

Treatment	Tef yield (kg/ha)	Weed dry matter (kg/ha)	Tef biomass (kg/ha)	Plant height at maturity (cm)	Harvest index
TRAD	1173 (50) a	77 (4) c	6.7 (0.18) a	44 (2.5) a	0.18 (0.007) b
TERW	925 (99) b	125 (10) b	4.5 (0.64) b	39 (3.5) b	0.21(0.007) a
PB	678 (73) c	242 (17) a	3.0 (0.69) b	31(1.7) b	0.22 (0.004) a

Conclusion

This short-term research showed improvement in SOM and aggregate stability in PB compared to the other treatments, although the difference was not significant. However, the SWRC shows that PB and TRAD had relatively higher moisture content near saturation compared to TERW. The relatively higher MacPOR of PB showed that the increase in the SOM and aggregate stability have contributed to this improvement. However, the PAWC of the treatments did not show a large difference. It is known that significant changes in some soil physical properties can be more prominent when the experiments are continued for longer periods of time. Despite the above improved soil physical properties, which most probably resulted in higher soil water storage in PB than in the other treatments, yield, biomass and plant height of teff were significantly higher in TRAD than in PB. The significantly high weed dry matter at first weeding in PB, the types of weeds and their water uptake behaviour may have caused the reduced teff yield. Herbicides must be used while growing teff in CA experiments.

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