Building resilience against drought and soil erosion: impact of field water conservation in the drought prone Vertisol areas of northern Ethiopia

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ABSTRACT

Field water conservation practices are a way forward to build resilience against drought through increasing productive green water and crop yield, while reducing runoff (blue water) and soil erosion. A long-term tillage experiment was carried out (2005 to 2011) on a Vertisol to quantify the impact of field water conservation practices on soil moisture, runoff, soil loss and crop yield in a rainfed field in northern Ethiopia. The experimental layout was a randomized complete block design with three replications on permanent plots of 5 m by 19 m. The tillage treatments were (i) *derdero+* (DER+) with a furrow and permanent raised bed planting system, 30% standing crop residue retention and no-tillage on top of the bed, (ii) *terwah+* planting system (TER+) with ploughing once at sowing, 30% standing crop residue retention and fresh broad beds, and (iii) conventional tillage (CT) with a minimum of three tillage operations and removal of crop residues. The crops grown in rotation were wheat, barley, teff and grass pea. The field conservation practices thus combined indigenous conservation practices (*derdero* and *terwah*) with the concepts of conservation agriculture (hence the '+'). Data on soil loss, runoff, soil moisture, crop yield and NDVI were collected. Significantly different ($p<0.05$) mean soil losses of 4.4, 12.5 and 18 t/ha/y were recorded for DER+, TER+ and CT, respectively. Similarly, the mean runoff was 458, 706 and 925 m^3/ha/y from treatments with DER+, TER+ and CT, respectively. The average grain yield of wheat over three years was 2.46, 2.02 and 1.61 t/ha for DER+, TER+ and CT, respectively. NDVI records in wheat and grass pea were higher in DER+.

INTRODUCTION

Soils in Ethiopia are conventionally ploughed repeatedly, crop residue is removed completely at harvest leaving no soil cover and aftermath overgrazing of crop fields is common, which results in aggravated land degradation. This has led in the long term to reduced soil organic matter content which later increased soil erosion processes (FAO 2010) and increased runoff and reduced soil water availability, thereby reduced land productivity. The limited and erratic precipitation in the semi arid areas of northern Ethiopia often results in low crop yields and sometimes in total crop failures. This low yields or total failure is associated with an imbalanced soil hydrology. Much rainwater is lost as blue water, i.e. as direct runoff, and in case of Vertisols as bypass flow out of the rootzone through cracks. Consequently, less water is available for crops, the so called productive green water (Rockström, 1997). This imbalanced soil hydrology can be due to physical deterioration of the soil quality and absence of effective in-situ soil and water conservation measures in the cropland itself. In addition, the green water has the productive part or transpiration involved in biomass production and the nonproductive part or evaporation. Drought-prone environments have shown that meteorological dry spells are important causes of low yield in sub Saharan African. Also periodic water logging and high runoff rates are problems in Vertisols. Water productivity in rainfed agriculture will have to increase appreciably in sub Saharan Africa if food production is to feed the current and the fast growing population in the region. Therefore, in order to increase crop productivity, soil and water management practices need improvement in Ethiopia.

Traditional *in situ* conservation tillage practices such as *terwah,* with contour furrows at 2-4 m wide intervals, and *derdero* planting systems are used by farmers in the northern Ethiopian highlands in which the former are used for teff and the latter for fenugreek, wheat and teff on Vertisol. Crops in *derdero* are grown on the ridges where they are protected from water logging (Nyssen et al. 2011).

Using Conservation Agriculture (CA) concepts in combination with traditional conservation practices can be a possible solution to increase green water, thereby increase crop productivity (1) by reducing tillage, (2) by retaining rational amounts of crop residue in the field and (3) by using profitable crop diversification (Sayre, 1998). However, results from comparison of CA and conventional agricultural practices over different time periods have not been consistent between socioeconomic setup, crops, tillage implements and systems, soils, climate, and experiments in different parts of the world (Ahuja et al. 2006; Giller et al. 2009). Therefore, in order to develop sustainable crop production systems, two modified versions of potential soil management practices, *derdero* ("*derdero+*") and *terwah* ("*terwah+*") local tillage systems using the traditional *mahresha* ard plough were introduced on Vertisols in Adigudem in northern Ethiopia since 2005.

The objective was to evaluate the mid-term effects of newly developed versions of traditional tillage systems combined with CA concepts on soil and water conservation, and crop yield.

MATERIALS AND METHODS

The study area and experimental field

The experiment was conducted under rainfed conditions from 2005 to 2011 in Adigudem (13°14'N, 39°32'E) in northern Ethiopia at an altitude of 2100 m a.s.l. Mean annual rainfall of 31 years in Adigudem was 499 mm with more than 85% from mid June to mid September. Three to six tillage operations are conventionally done with an oxen-drawn ard plough to control weeds, improve infiltration and prepare a fine seedbed. The experimental layout was a randomized complete block design with three replications (Fig. 1). The plot size was 5 × 19 m with a slope gradient of 3%. Crops grown in rotation were wheat, teff, barley and grass pea. The same plots were kept fixed during the seven years of study. Weed control was done by hand weeding in the first two years in TER+ and DER+, whereas from 2007 on non-selective herbicide glyphosate (N-(phosphonomethyl) glycine) was sprayed at 2 L/ha three to four days before planting to control pre-emergent weeds.

Three tillage practices were applied: (1) conventional tillage (CT) was ploughed at least three times per year and the crop straw was completely harvested without leaving crop residues on the surface; (2) *terwah+* (TER+) was a new tillage system developed from a traditional *in situ* water conservation practice, making furrows on the contour at regular intervals of ca. 1.5 m, using only one ploughing operation and leaving 30% standing stubble; (3) *derdero+* (DER+) is another newly developed tillage system which is based on another traditional *in situ* water conservation technique, makes beds and furrows along the contour at intervals of ca. 0.6 m. The 'plus' in *derdero+* and *terwah+* stands for the CA-related improvements made.

Data collected

Runoff was measured in 4.5 m long, 1.5 m wide (at the top) and 1 m deep collector trenches (Fig. 1), which were located at the down slope end of each plot and lined with thick plastic sheets following the method explained in Tesfay et al. (2011). Rainfall was recorded daily at 8:00 AM by rain gauge. Changes in soil water storage were quantified using gravimetric water content method recorded at regular times at soil depths of 20, 40, 60, 80 and 100 cm. Gravimetric water content was converted to volumetric water content using bulk density calculated using soil shrinkage characteristic curve.

Grain and straw crop yield were determined at harvest from 1 × 1 m areas in three replicates per plot.

Statistical analysis

ANOVA was used to test the statistical differences of the different parameters of the treatments. The data was analyzed using SAS statistical software (JMP version 5.0) and standard error of treatment means was used for separation of treatment means (SAS Institute Inc., 2002). Mean comparison for parameters was carried out by a Student t-test at $\alpha = 0.05$.

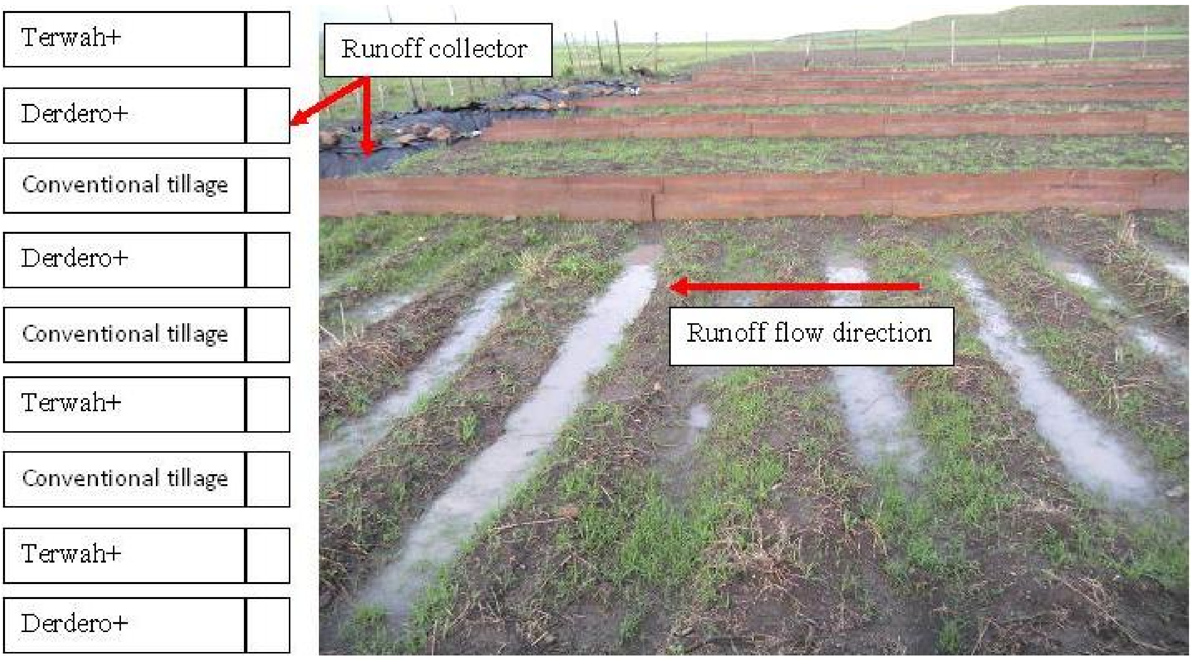

Figure 1. Layout of the experimental plot at Adigudem, northern Ethopia in August 2010: the crop is teff in the second week after planting

Table 1: Grain and straw yield from 2005-2011 (n = 3) for the experimental site in Adigudem, Ethiopia (p<0.05).

Year	Crop	Treatment	Grain yield (t/ha) Mean ± SEM	Straw yield (t/ha) Mean ± SEM
2005	Wheat	DER+	2.03±0.21a	6.18±0.92a
		TER+	1.97±0.15a	5.99±0.31a
		CT	1.53±0.06a	4.25±0.61a
2006	Teff	DER+	0.68±0c	2.37±0.13ab
		TER+	0.93±0.02b	3.08±0.07b
		CT	1.17±0.02a	3.75±0.2a
2007	Wheat	DER+	2.76±0.08a	5.19±0.12a
		TER+	2.20±0.06b	4.31±0.2ab
		CT	1.70±0.02c	3.45±0.32b
2008	Barley	DER+	0.69±0.02a	0.54±0.01a
		TER+	0.57±0.02b	0.34±0.03b
		CT	0.53±0.02b	0.24±0.03b
2009	Wheat	DER+	2.60±0.06a	5.20±0.13a
		TER+	1.90±0.05b	4.20±0.05b
		CT	1.60±0.04c	3.70±0.12c
2010	Teff	DER+	1.53±0.06a	4.25±0.08a
		TER+	1.55±0.04a	4.45±0.22a
		CT	1.42±0.04a	4.03±0.28a
2011	Grass pea	DER+	1.76±0.04a	2.03±0.07a
		TER+	1.66±0.04a	1.99±0.06a
		CT	1.31±0.08b	1.59±0.03b

RESULTS

Runoff and soil loss were significantly reduced while soil moisture and crop yield were improved in DER+ followed by TER+ planting system compared to CT (Fig. 2, Fig. 3 and Table 1). NDVI records were higher in DER+ in wheat and grass pea while higher in TER+ in teff (Fig. 4).

DISCUSSION

Over the seven consecutive monitored years, DER+ significantly ($P<0.05$) reduced runoff, runoff coefficient and soil loss, followed by TER compared to CT (Fig. 2). Runoff reduction in CA treatments indicates the potential to reduce rain water loss as blue water in the form of runoff in DER+ and TER+ planting system. The consistently smaller runoff coefficients in DER+ were likely due to the capacity of the 30-40 cm wide furrows to retain a large proportion of runoff as depression storage (Fig. 2; Sayre 1998). Soil water storage was higher in DER+ indicating an increment in green water. Retention of crop residues on DER+ also contributed to a significant decline in soil loss, runoff and increment in soil moisture (Fig. 3) which accords with other findings (Erenstein 2002). Moreover, in the DER+ planting system, excess rain water drain to the furrow storage from the raised beds without affecting the crop grown on top of the raised bed.

In addition, this study demonstrated that CA treatments are promising for the farmers on Vertisol with equal or higher crop yield in CA systems than CT during the seven years study period except for teff in the second year (2006) (Table 1). Habtegebrial et al. (2007) reported that reduced tillage can be an option in teff production in Vertisol. Improvements in crop yield in CA treatments required a period of at least three years of cropping before they became significant, which was faster to the findings by Tesfay et al. (2012). Unlike 2006, the yield of teff was higher in TER+ followed by DER+ compared to CT in 2010. The main reasons for lower teff yield in CA treatments in 2006 could be firstly the absence of chemical weed control which resulted in unsuppressed weed growth and yield losses. In this study, the use of glyphosate herbicide as of 2007 in CA plots greatly declined weed population in every additional study year by reducing the weed seed bank in the soil. DER+ planting system had performed best both under favourable and unfavourable (e.g. 2008) weather conditions. NDVI records in wheat and grass pea were higher in DER+ while higher in TER+ in teff indicating the direct positive correlation with crop yield.

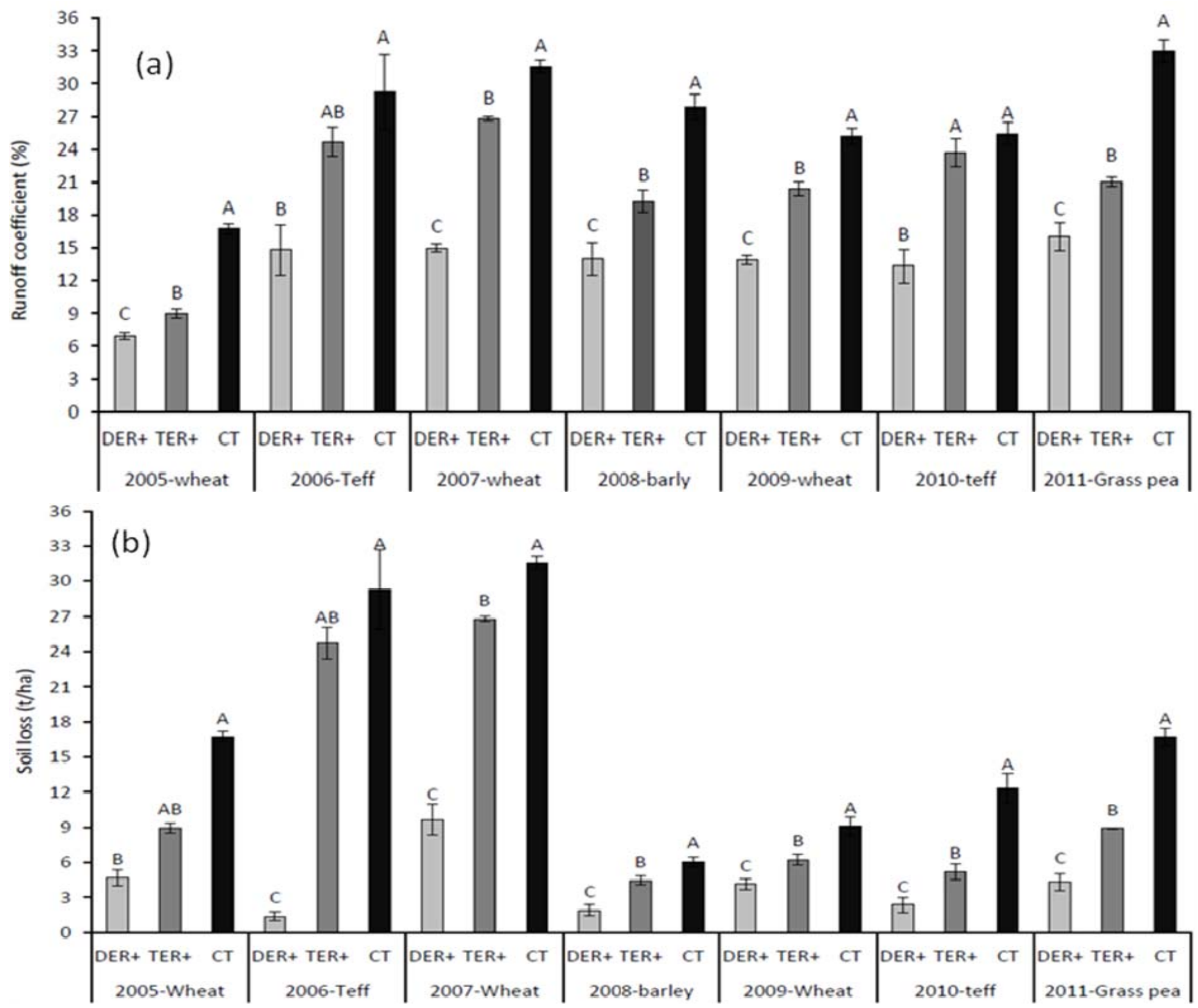

Figure 2. Mean yearly runoff coefficient (a) and soil loss (b) from each treatment throughout the growing period (n = 6) from 2005-2011. DER+ is derdero+, TER+ is terwah+, CT is conventional tillage practice, SEM is standard error of mean (p<0.05)

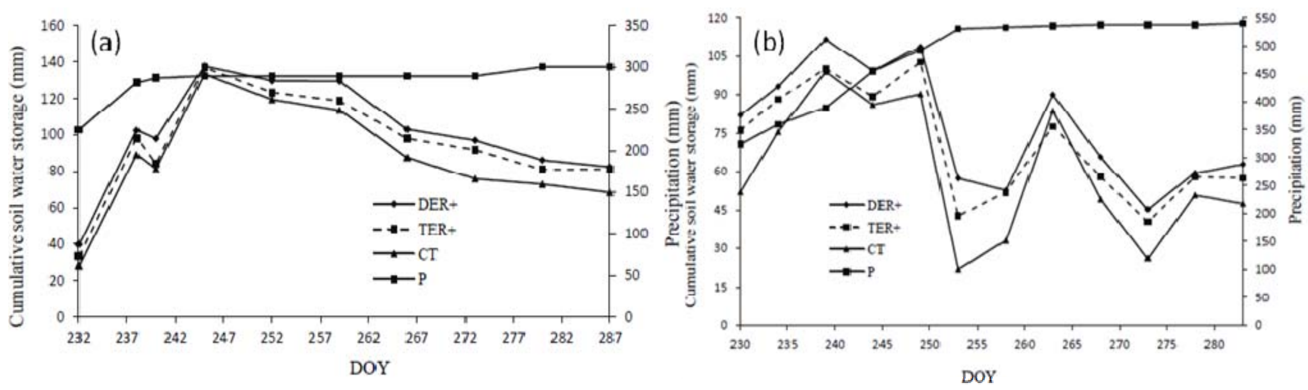

Figure 3. Soil water storage at 90 cm soil depth determined using gravimetric water content in 2009 (a) and 2010 (b). DER+ is derdero+, TER+ is terwah+, CT is conventional tillage practice, P is precipitation, DOY is day of the year.

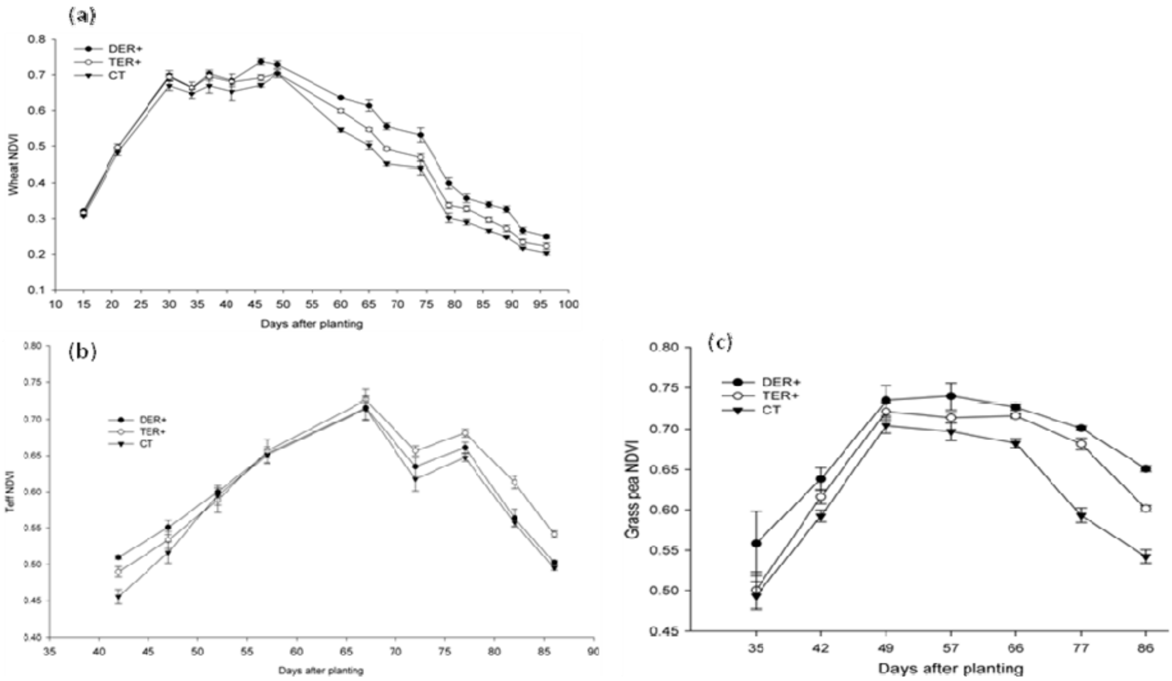

Figure 4. Normalized Difference Vegetative Index (NDVI) of (a) wheat (2009), (b) teff (2010) and (c) grass pea (2011)

CONCLUSION

The results of this study indicated that improved local tillage practices of DER+ and TER+ planting system can be an alternative to the CT system to reduce runoff and soil loss and improve soil moisture and crop yield on Vertisol. The DER+ planting system performed better even during unfavourable weather conditions compared to the other treatments. However, the improvement in soil physical, chemical and biological properties is not immediate and the full benefit of DER+ with permanent raised beds plus retention of crop residues can only be expected after several years. Therefore, farmers in the northern Ethiopia can reduce runoff and soil loss, improve soil moisture and crop yield in Vertisols by adopting improved good local practices of DER+ and TER+ planting systems that employ conservation agriculture principles.

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