24. Soil and water conservation through introduction of conservation agriculture in Dogua Tembien

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Introduction

Land degradation in northern Ethiopia is caused by the complete removal of crop residues at harvest, open grazing of livestock after harvest, and intensive tillage. This has led to reduced soil organic matter which further increases soil erosion and reduces land productivity. The livelihood of 85% of the population of Tigray in northern Ethiopia depends on agriculture, mainly on crop production, and small units of land have been extensively cultivated by subsistence farmers for centuries. Rainfed farming is dominant and has low productivity due to erratic and insufficient rainfall during the growing season. Problems arise from periodic drought, water logging, high tillage frequency, and high runoff rates. Frequent tillage increases loss of soil organic matter because of mixing of soil and crop residues, disruption of aggregates, and increased aeration. Under wet conditions, Vertisols are very susceptible to erosion which is considered to be the major limitation to long-term production. In order to increase crop productivity, soil moisture regimes need improvement. The keeping of large numbers of cattle associated with intensive conventional tillage has caused land degradation by overgrazing. In addition, farmers use the straw as fodder and leave no residues as soil cover. Nyssen *et al.* (2007) report that soil and water conservation structures such as stone and soil bunds are effective. Recent policy in Tigray favours further *in situ* water conservation, stubble management and the abandonment of free grazing (Nyssen *et al.*, 2011). However, until recently there was no practice of implementing conservation agriculture (CA) in Tigray. According to FAO (2010), “CA is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. CA is characterized by three principles which are linked to each other, namely continuous minimum mechanical soil disturbance, permanent organic soil cover, and diversification of crop species grown in sequence or associations.” Various studies on CA outline many benefits, including early planting, growing long maturing crops/varieties, runoff and evaporation reduction, soil loss reduction, soil moisture conservation, increased labour efficiency, reduced oxen and straw demand, and enhanced soil fertility (Govaerts *et al.*, 2007). In contrast to conventional agriculture, CA involves the leaving of residues from the previous crop on the soil surface to improve water storage and increase surface roughness. However, results from comparison of CA and conventional agricultural practices over different time periods have

not been consistent between crops, ploughs, soils, climate, and experiments in different parts of the world (Ahuja *et al.*, 2006). Permanent raised bed (PB) (Fig. 1) and reduced tillage (RT) systems using the traditional marasha ard plough, were introduced in Tigray in 2005 on Vertisols to improve water conservation, reduce runoff and soil erosion, and to increase crop yield. In May Zeg-zeg, where free grazing has been abolished, the developed PB or *derdero+* technology (Fig. 1) has also been implemented on ten farmers' fields with a total area of around 2 ha, with good results in terms of crop stand and crop yield, and strongly reduced draught requirement both in number of tillage operations and in required energy (Fig. 2).
The objective of this study was to evaluate the effect on runoff, soil loss and crop yield of the different CA tillage systems in Vertisols in Tigray.

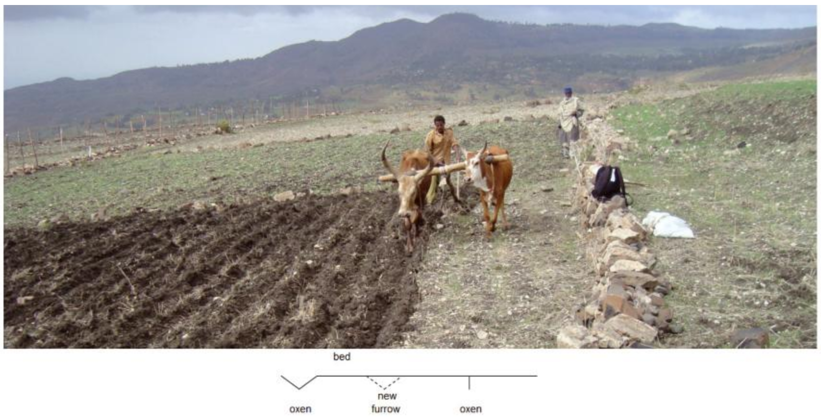

Fig. 1. The PB or derdero+ system involves shaping of beds and furrows by a pair of draught animals with attached marasha (on a farmer's field in May Zeg-zeg, July 2009). Only a single, broad-spaced tillage operation is needed. The farmer replaced one of the oxen in the span by a (weak) cow, as only the sediment accumulated in the previous year's furrows needed to be reworked and less power was needed. Note how the left ox walks in the furrow, which provides guidance for the position of the plough tine in the immediately upslope furrow (After Nyssen et al., 2011).

Fig. 2. Wheat stand on farmers plots tilled according the Derdero+ system. Location: the excursion point in Hechi, in October 2010.

Materials and methods
The study area. The experiment was conducted under rainfed conditions from 2005-2010 in May Zeg-zeg (13°39'N, 39°10'E) at an altitude of 2550 m a.s.l. in Tigray, northern Ethiopia. Mean annual rainfall of May Zeg-zeg is 767 mm with more than 80% from mid June to mid September.

The field experiment. The experimental layout was a randomized complete block design with three replications. The plot size was 5 x 14 m and the slope 6.5%. The soil under the experimental trial was a Vertisol. The tillage treatments were (1) conventional tillage (CT), where the soil is ploughed three times per year to create a fine seedbed and with the crop straw being completely harvested without leaving crop residues on the surface, (2) terwah (RT), a traditional in situ water conservation method especially used in tef where broad seedbeds are created using the marasha ard plough by making furrows on the contour at regular intervals of ca. 1.5 m (Nyssen et al., 2011), but which is in the context of this study also tested for crops other than tef and leaving standing stubble, and (3) a newly developed tillage system we called *derdero+* (or PB, permanent beds), which is based on another traditional in situ water conservation technique derdero, where at the last tillage operation, the farmers broadcast the seeds over the surface and then prepare beds and furrows along the contour using the marasha, moving the soil and seeds to an upper position on the beds (Nyssen et al., 2011). It protects the crops from waterlogging, while excess water drains towards the furrows where it can slowly infiltrate. The 'plus' in derdero+ stands for the improvements made, including the introduction of permanent beds with standing stubble (>30%), where furrows are prepared on the contour at intervals of ca. 0.6 m. At sowing, seeds are broadcasted over the land and the furrows reshaped, moving the soil to the beds and covering the seeds. Crops grown, from the first to the sixth year were wheat, grass pea, wheat, *hanfets* (wheat and barley sown together), grass pea and wheat. The seed and fertilizer rates were similar for all treatments. Urea fertilizer was not applied to grass pea. The same plots were kept fixed during the six years of study. Weed control was by hand weeding. Non-selective herbicide glyphosate (N-(phosphonomethyl) glycine) was sprayed starting in 2007 at 2 L ha^{-1} three to four days before planting to control pre-emergent weeds.

Fig. 3. Partial view of the experimental plot at Adi Gudom. On a daily base in the rainy season, and after measurements and samples are taken, the collector trenches are emptied. The runoff plots are located at left.

Data collected. Runoff and soil loss were measured in 4.5 m long, 1.5 m wide (at the top) and 1 m deep collector trenches (Fig. 3), which were located at the down slope end of each plot and lined with thick plastic sheets. The plots were separated by 0.50 m wide ditches to avoid surface or subsurface flow between plots. Runoff data were collected at 8:00 AM after each rainfall event by measuring the height of the water at three sample locations in the trenches. The volumes of the trenches were annually calibrated at the middle of the growing season by relating known amounts of water to depth at three sample locations in the trench following the method of Gebreegziabher *et al.* (2009) and Oicha *et al.* (2010). Rainfall was recorded daily at 8:00 AM by rain gauge The collected runoff water was stirred thoroughly and 4 L taken from each trench to determine accumulated sediment in the trenches of each plot. These were filtered using a funnel and Whatman 42 filter paper having a pore size of 2.5 μm. The sediment in the filter paper was oven dried for 24 hours at 105 °C and weighed to quantify soil loss. Grain and straw crop yield were determined at harvest from areas of 2 x 8 m and 2 x 6 m in two replicates per plot.

Statistical analysis. ANOVA was used to test for statistical differences in runoff, soil loss and crop parameters between the management treatments. Data were analyzed using the SAS statistical software (JMP version 5.0), and the standard error of treatment means was used for separation of means. Comparison of means was carried out by Student *t*-tests at $\alpha = 0.05$.

Results and discussion

Runoff and soil loss. Runoff was lowest in PB during the complete study period and it was significantly different ($P<0.05$) in 2007 and 2010 when wheat was grown, with the largest record from CT, followed by RT (Fig. 4b). Mean runoff during the rainy seasons (three months) of the five study periods was 900, 1011 and 1091 $m^3\ ha^{-1}$ from PB, RT and CT, respectively. The highest amount of runoff was observed in 2005 followed by 2006. Five years mean runoff coefficients were 23, 26 and 28% in PB, RT and CT, respectively (Fig. 4c).

Soil loss was significantly different ($P<0.05$) between treatments and in all years except in 2005. Variations across years may be related to crop type and rainfall amount, intensity and distribution. A 4-year mean soil loss of 14, 17 and 24 t ha^{-1} was recorded from PB, RT and CT, respectively (Fig. 4d). The highest soil loss was produced during the grass pea cropping season in 2009, which is related to late sowing date and low vegetation cover of this plant.

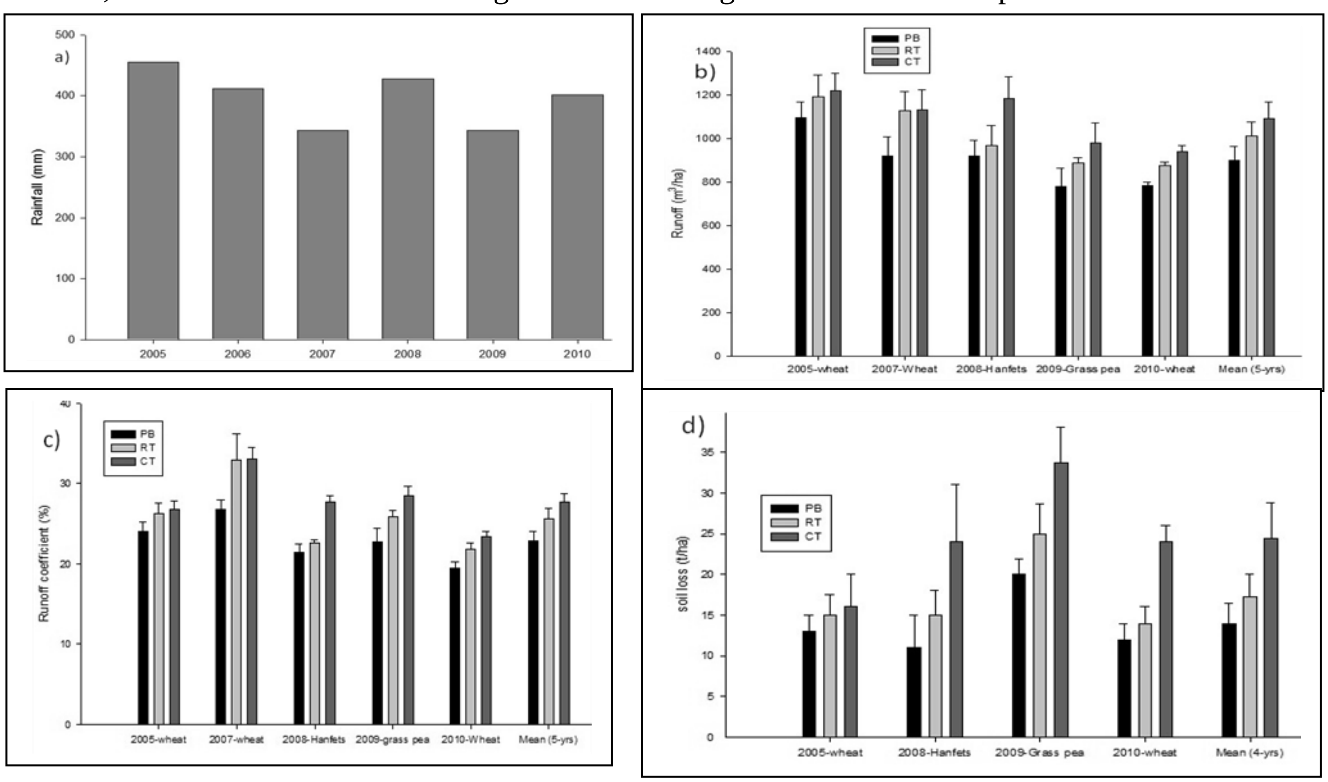

Fig. 4. Rainfall during growing season (a), mean runoff (b), runoff coefficient (c) and soil loss (d) from each treatment throughout the growing period. PB is permanent raised bed, RT is reduced tillage, CT is conventional tillage. The bars shown represent standard error of mean (P<0.05).

Crop performance. Grain yield improvements have become consistent after a period of four years of cropping in CA type treatments, i.e. from 2009 on (Table 1). Grain and straw yield of grass pea in CT was found to be significantly higher in 2006. In 2009, highest grass pea grain and straw yield were observed in RT, whereas in 2010 PB resulted in highest wheat grain and straw yield. Plant height is larger in PB throughout the growing season but especially in the beginning of the rainy season, when, unlike in CT, growth in PB remains unaffected by short dry spells (Fig 5.)

Table 1. Grain and straw yield from each treatment. PB is permanent raised bed (or Derdero+), RT is reduced tillage, CT is conventional tillage, SEM is standard error of mean (P<0.05).

year	Crop	Grain yield (t/ha) (mean ±SEM)			Straw yield (t/ha) (mean ±SEM)		
		PB	RT	CT	PB	RT	CT
2005	Wheat	3.1±0.2A	2.7±0.2A	2.8±0.1A	-	-	-
2006	Grass pea	2.1±0.1B	2.1±0.1B	2.9±0.2A	2.8±0.1B	2.9±0.1B	4.1±0.2A
2007	Wheat	2.9±0.1A	2.9±0.2A	3.0±0.3A	6.8±0.3A	6.7±0.6A	6.9±0.8A
2008	*Hanfets*	2.0±0.1A	1.9±0.1A	1.9±0.1A	3.1±0.1A	3±0.2A	3±0.2A
2009	Grass pea	2.2±0.2AB	2.8±0.1A	2.0±0.2B	3.9±0.4AB	4.4±0.2A	3.5±0.3B
2010	Wheat	5.2±0.1A	4.5±0.15B	4.0±0.2C	6.7±0.7A	5.3±0.6B	4.7±0.1C
Mean (2yrs)	Grass pea	2.2±0.2A	2.4±0.1A	2.5±0.2A	3.4±0.3A	3.6±0.2A	3.8±0.2A
Mean (3yrs)	Wheat	3.7±0.1A	3.4±0.2AB	3.2±0.2B	6.7±0.5A	6±0.6AB	5.8±0.5B
Mean (6yrs)	All crops	2.9±0.1A	2.8±0.1A	2.8±0.2A	4.2±0.2A	4±0.2A	4±0.2A

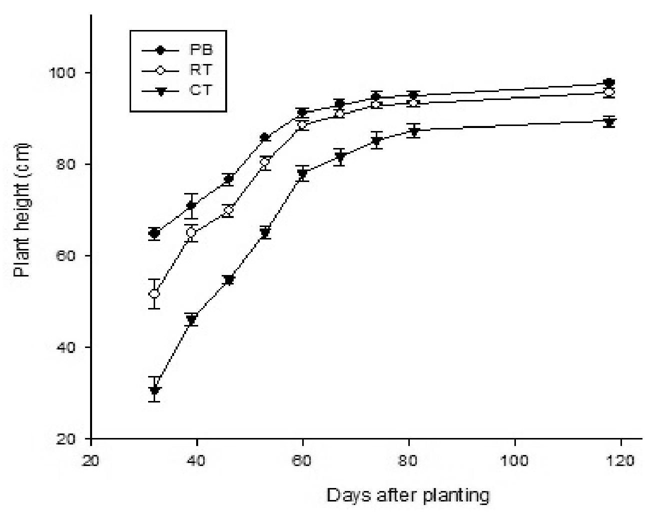

Fig. 5. Plant height of wheat in growing season of 2010

Farmers in the area planted grass pea late in the cropping season to avoid excessive soil moisture conditions which may explain the presence of lower yield in PB. To increase grain yield further in PB may require adjustments in planting time. The mean of two years grass pea did not show significant yield differences, whereas the mean of three years wheat did show a significant yield difference (P<0.05). The total mean grain and straw yield of all crops in the six years (wheat, *hanfets* and grass pea) were found to be higher in PB, but not with significant difference. The grain and straw yield of improved wheat variety in 2010 was significantly higher in PB followed by RT.

Conclusion

A permanent raised bed planting system with retention of crop residues and to a lesser extent a reduced tillage system was found to be beneficial for raising wheat grain and straw yields, and reducing runoff and soil loss in 2010 in northern Ethiopia. Reduced tillage increased grain yield of grass pea in 2009. Overall, the permanent raised bed planting system with crop residue retention can be an efficient soil and water conservation strategy through reducing the runoff coefficient and draining excess water from the beds through furrow storage. This approach also reduces soil loss and improves soil fertility, thus increasing crop productivity and avoiding further land degradation. However, the improvement in soil physical, chemical and biological properties is slow and the full benefit of permanent raised beds plus retention of crop residues can only be expected after several years. Our results demonstrate the importance of PB in increasing wheat yield and reducing soil loss and runoff. Planting time adjustments in PB treatments can be possible suggestion to further increase grass pea yield. However, the reduced tillage system can also be recommended as a first step for reducing runoff and soil loss and whilst increasing crop yield. The long-term goal should be to achieve a permanent raised bed planting system along with use of crop residues.

Taking into account the reduced input in terms of human and oxen labour, farmers in the study area are now planning to expand the system to the scale of sectors of their village territory.

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