

Impact of conservation agriculture on runoff, soil loss and crop yield on a Vertisol in the northern Ethiopian highlands

Tesfay Araya^A, Wim M. Cornelis^B, Jan Nyssen^C, Bram Govaerts^D, Tewodros Gebregziabher^E, Tigist Oicha^E, Fekadu Getnet^E, Dirk Raes^F, Mitiku Haile^E, Ken D. Saire^D and Jozef Deckers^F

^ADept. of Crop and Horticultural Science, Mekelle University, P.O. Box 231, Mekelle, Ethiopia.

^BDept. of Soil Management - International Centre for Eremology, Ghent University, Coupure links, 653, B-9000 Gent, Belgium.

^CDept. of Geography, Ghent University, Krijgslaan 281 (S8), B-9000 Gent, Belgium.

^DInternational Maize and Wheat Improvement Centre (CIMMYT), A.P. 6-641, Mexico D.F. 06600, México.

^EDept. of Land Resources Management and Environmental Protection, Mekelle University, P.O. Box 231, Mekelle, Ethiopia.

^FDept. of Earth and Environmental Sciences, Katholieke Universiteit Leuven, Celestijnenlaan 200E, B-3001, Belgium.

Abstract

Conservation Agriculture (CA) can be a possible technique to mitigate the reduction in soil quality, to reduce runoff and soil erosion, and can increase in situ moisture conservation, thereby increasing crop yield. This study was carried out on a rainfed field in Tigray, northern Ethiopia. The objective was to evaluate the impacts of CA on runoff and soil loss, and crop yield improvements. The CA practices were introduced on farmers' fields on vertisols since 2005. The experimental layout was arranged according to a randomized complete block design with two replicates. Treatments included conventional tillage (TRAD) which was ploughed 3 times and residue removed, *Terwah* (TERW) ploughed 3 times, residues removed and furrows made at 1.5 m distance, and permanent beds (PB) with 30% residue retention, zero tilled and 60 cm wide bed size. All the ploughing and reshaping of the furrows was done using the local ard plough *maresha*. Data on soil loss, runoff and grain yield were collected. The crops in rotation were wheat and teff. There was significant reduction ($p < 0.05$) in runoff in PB under wheat in 2005, whereas the reduction was non-significant in 2006 and 2007. The soil loss was significantly lower in PB in 2005 and 2006. Soil loss in 2005 under wheat was reduced by 76% in PB and 61% in TERW as compared to TRAD. Similarly, the reduction in soil loss in 2006 under teff was 86% in PB and 53% in TERW. There was no significant difference ($p < 0.05$) for wheat yield in 2005 and 2007. However, there was a significant difference among treatments in 2006 with higher teff yield in TRAD followed by TERW. In summary, permanent bed reduced soil loss and runoff and hence increased yield of wheat. Yield of teff was, however, reduced with permanent beds.

Key Words

Conservation agriculture, *Terwah*, permanent bed, crop residue, wheat, teff

Introduction

Land degradation in northern Ethiopia is a great problem mainly aggravated by overpopulation in the highlands, over cultivation, soil erosion, and an unbalanced crop and livestock production system (Girma 2001). As a consequence of loss of the top fertile soil by erosion, there is severe decline in soil quality. The poor infiltration and water holding characteristics of the soil makes water a key limiting factor for crop yield in this area. The livelihood of 85 % of the population of Tigray depends on agriculture, mainly on crop production, and small units of land have been extensively cultivated by subsistence farmers for centuries. The rainfed farming agriculture is dominant and has low productivity. The rainfall in the region is erratic and insufficient during the growing season (Ermias *et al.* 2005). It is common to observe both water logging and drought in one cropping season (personal observation). Soil moisture in the Vertisols is insufficient due to periodic drought, low moisture holding capacity of the soils, high tillage frequency, and high runoff rates from sloping lands in case of periodic excess of rain water (Mati 2006). Tillage is done with a breaking plough locally known as *mahresha* with frequent ploughing before sowing which may result in compaction, poor drainage and crusting in Vertisols. Also, farmers harvest the straw of crops in order to feed their animals leaving no residues as soil cover. There is also free grazing of animals on the stubble residue after harvest. These operations have led to the long term reduction in soil organic matter content which consequentially increased soil erosion. Recent policy in Tigray region favours in situ water conservation, stubble management and the abandonment of free grazing. Vertisols are hard when dry, very sticky when wet and susceptible to erosion depending on how they are managed and on their top soil structure and texture (Deckers *et al.* 2001). McHugh *et al.* (2007) reported that ridges significantly increased soil moisture and grain yield and reduced soil loss in north Wollo, Ethiopia. Experiments conducted in Mexico by Govaerts *et al.* (2005) on a fine, mixed, thermic, Cumulic Haplustoll with zero tillage treatment combined with rotation

and residue retention showed improvements in yield as compared to heavy tillage before seeding, monocropping and crop residue removal. They reported that permanent bed with crop rotation and residue yielded the same as zero tillage. Various studies on CA outlined many benefits as it allows early sowing, growing long maturing crops/varieties, reduces runoff and evaporation, reduces soil loss, conserves soil moisture, increases labour efficiency, reduces oxen and straw demand, and enhances soil fertility (Nyssen *et al.* 2006). In contrast to traditional agriculture, conservation agriculture leaves residues from the previous crop on the surface. It may store a considerable amount of water and increases roughness, slowing down the runoff flow velocity (Findeling *et al.* 2003). However, comparison of conservation agriculture and traditional agriculture practices over different time periods have not been consistent across soils, climate, and experiments in different parts of the world (Ahuja *et al.* 2006). Conservation agriculture and other CA based resource conserving technologies practices like permanent bed and modified *terwah* tillage systems were introduced in Adigudom, Tigray, Ethiopia for the last three years since 2005 with the aim to conserve moisture, reduce runoff and soil loss on farmers' fields, hence increasing crop yields on Vertisols. In Tigray, farmers use to make contour furrows at 2-4 m interval, locally called *terwah*, usually on teff to trap water for later crop use instead of being lost as runoff. Therefore, the objective of this study was to evaluate runoff and soil loss, and crop yield under conservation and conventional agriculture in Tigray, northern Ethiopia. Short-term effects on physical soil quality are reported elsewhere (Oicha *et al.* 2010a,b).

Material and methods

Study site

The experiment was conducted under rainfed conditions starting in 2005 in Adigudom (13°14'N, 39°32'E), Tigray, Northern Ethiopia. Tigray is characterized by a cool tropical semi arid climate, with recurrent drought induced by moisture stress. The mean annual rainfall (26 yr) is 505 mm, with more than 85% falling from June to September. Rainfall intensity can be very high, with about 60% of the rain having intensities of over 25 mm/h. Mean annual temperature is 23 °C and mean annual evapotranspiration amounts to 1539 mm. Sowing begins in mid June and harvesting ends in December. The farming system in the region is a mixed farming system with both crop and livestock. The main crops grown in Adigudom are teff (*Eragrostis tef.*), wheat (*Triticum sp.*), barley (*Hordeum sp.*), hanfets (mixture of barley and wheat), sorghum (*Sorghum bicolor* (L.) Moench), millet (*Eleusine coracana*), maize (*Zeamays L.*) and lentil. The sowing method is generally broadcasting manually.

Experimental layout

The experimental layout was arranged as a randomized complete block design with two replications. The plot size was 5 m wide and 19 m long. The sowing method was manual broadcasting for both crops (wheat and teff) that were grown during the three growing seasons under study (2005-2007). The slope gradient was 3%. The soil under the experimental trial 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. The different treatments were: (1) conventional tillage (TRAD) ploughed three times without residue, (2) Terwah (TERW) ploughed 3 times without residue and with furrows made at 1.5 m distance interval along the counter, and (3) permanent bed (PB) with 30% residue, zero tilled and 0.6 m wide beds. All the ploughing and reshaping of the furrows was made using *maresha*. Fertilizer was applied uniformly to all treatments. Glyphosate was applied to control pre-emerged weed in PB treatment. However, hand weeding was used as post emergence weed control in all treatments.

Data collected

Parameters such as runoff, soil loss and grain yield were collected. Runoff and soil loss were measured in 4.5 m long, 1.5 m wide (at the top) and 1 m deep collection trenches, which were located at the down slope end of each plot and lined with 0.5 mm thick plastic sheets. Runoff amount was determined at 8:00 am after each rainfall shower that caused erosion by measuring the height of the water level in the middle and at both sides of the trench. The trenches were calibrated for their volume by relating a known amount of water to water depth at the same three locations. The collected runoff water was then stirred thoroughly and 4 liter was taken from each trench to determine sediment concentration. These were filtered in the laboratory using funnel and Whatman # 12 filter papers. The sediment in the filter paper was oven dried for 24 hours at 105 °C and weighed. Grain yield was determined from 2 m by 8 m and 2 m by 6 m harvestable areas.

Results

Runoff and soil loss

There was a significant difference ($p < 0.05$) in runoff among all treatments in the first year (2005) for wheat, with less runoff recorded in PB followed by TERW. However, there was no significant difference for runoff among all treatments in the second and third year (2006 and 2007) when the crop was teff and wheat, respectively (Figure 1). Even though non-significant, in 2006, the PB treatment has revealed a reduction in 50% runoff followed by 16% in TERW. There was a very similar trend in 2007 when the crop was wheat as compared to 2006. There was significant difference ($p < 0.05$) in soil loss in 2005 and 2006 in wheat and teff, respectively. The soil loss reduction in 2005 for wheat was 76% in PB while 61% in TERW as compared to TRAD. Similarly, the reduction in soil loss was 86% in PB and 53% in TERW as compared to TRAD in 2006 for teff (Figure 2).

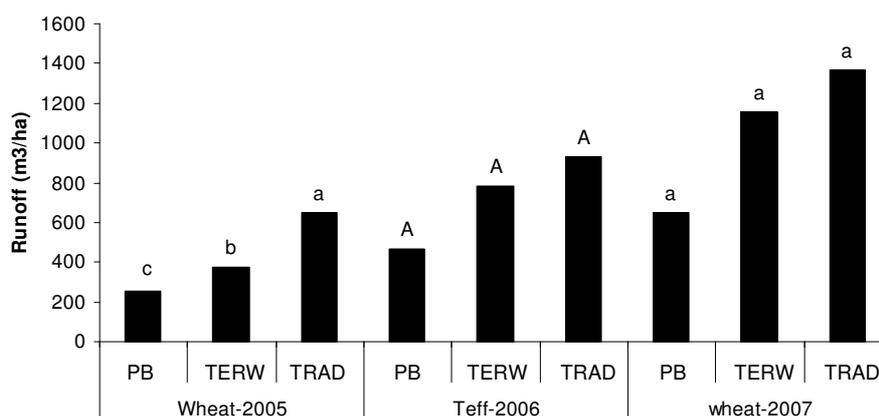


Figure 1. Average runoff amount from each treatment during the whole growing period across years in Adigudom. A letter on the top of each bar graph indicates the significant difference ($p < 0.05$) among treatments per one year. PB = permanent bed tillage; TERW = *terwah* tillage; TRAD = conventional tillage.

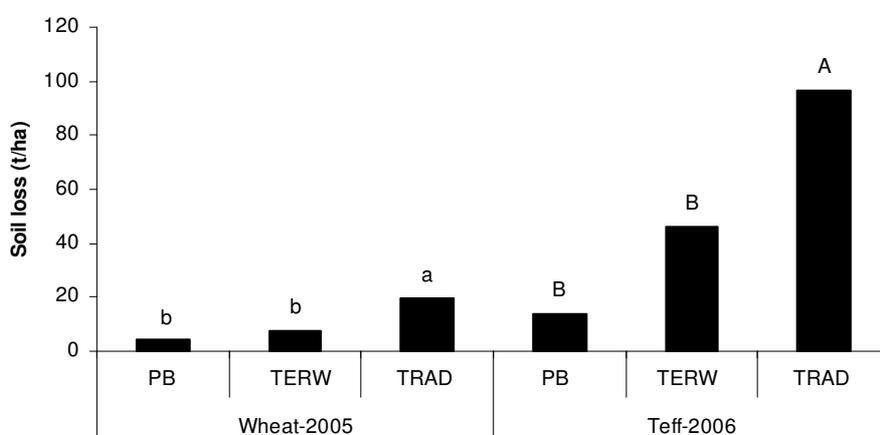


Figure 2. Average soil loss from each treatment during the whole growing period in 2005 and 2006 in Adigudom. A letter on the top of each bar graph indicates the significant difference ($p < 0.05$) among treatments per one year. PB = permanent bed tillage; TERW = *terwah* tillage; TRAD = conventional tillage.

Yield performance

There was no significant difference ($p < 0.05$) between treatments for wheat yield in 2005 and 2007. However, there was a significant difference among treatments in 2006 with higher teff yield obtained in TRAD followed by TERW. The lowest teff yield was recorded in PB. Although the difference was not significant, the yield of wheat in 2005 and 2007 showed that there was a higher yield record in PB followed by TERW. In contrast to the 2006 teff yield, the lowest wheat yield in both 2005 and 2007 was recorded in TRAD (Figure 3).

Conclusion

Based on the three years data, runoff was significantly reduced in PB followed by TERW as compared to TRAD in 2005. Although not significant, there was lower runoff in PB in 2006 and 2007. There was a significant difference for soil loss reduction which was lower in PB compared to TRAD. However, there was

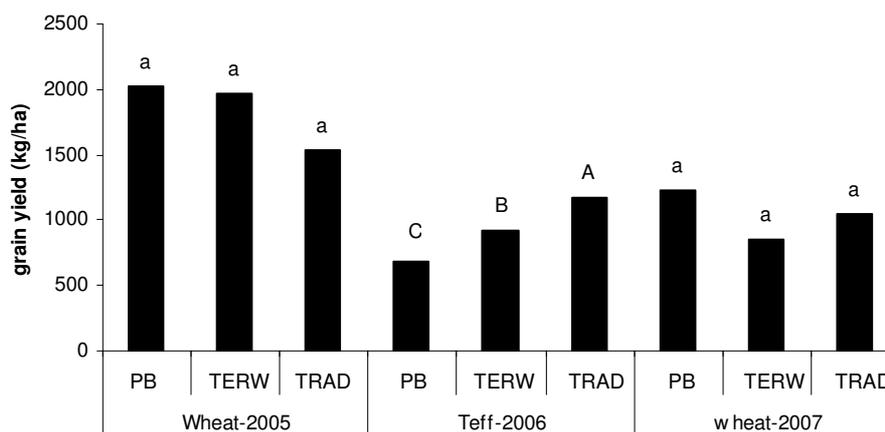


Figure 3. Average grain yield (kg/ha) trend in conservation and conventional agriculture across years in Adigudom. A letter on the top of each bar graph indicates the significant difference ($p < 0.05$) among treatments per one year. PB = permanent bed tillage; TERW = *terwah* tillage; TRAD = conventional tillage.

no significant difference for soil loss between PB and TERW. Although the difference was not significant, the yield of wheat showed increment increase in both in 2005 and 2007. The yield of teff in 2006 was significantly lower in PB as compared to TRAD, which could be attributed to weed manifestation under PB and TERW. Specific attention should be paid to weed control while growing teff in PB and TERW systems.

References

- Ahuja L, Ma L, Timlin D (2006) Trans-Disciplinary Soil Physics Research Critical to Synthesis and Modeling of Agricultural Systems. *Soil Science Society of America Journal* **70**, 311–326.
- Deckers J, Spaargaren O, Nachtergaele F (2001). Vertisol: genesis, properties and soil scape management. In 'The sustainable management of Vertisols' (Eds K Syers, F Penning de Vries, P Nymundeza) pp. 3-20 (CABI publishing: New York).
- Ermias A, Solomon A, Alemu E (2005) Small-scale reservoir sedimentation rate analysis for a reliable estimation of irrigation schemes economic lifetime. A case study of Adigudom area, Tigray, northern Ethiopia. Faculty of Dryland Agriculture and Natural Resources, Mekelle University.
- Findeling A, Ruy S, Scopel E (2003) Modeling the effects of a partial residue mulch on runoff using a physically based approach. *Journal of Hydrology* **275**, 49-66.
- Girma T (2001). Land Degradation: A Challenge to Ethiopia. *Environmental Management* **27**, 815-824.
- Govaerts B, Sayre KD, Deckers J (2005) Stable high yields with zero tillage and permanent bed planting? *Field Crops Research* **94**, 33-42.
- Mati BM (2006) 'Overview of Water and Soil Nutrient Management under Smallholder Rain-fed Agriculture in East Africa'. International Water Management Institute. Working Paper 105.
- McHugh OV, Steenhuis TS, Abebe B, Fernandes E (2007) Performance of in situ rainwater conservation tillage techniques on dry spell mitigation and erosion control in the drought-prone North Wello zone of the Ethiopian highlands. *Soil and Tillage Research* **97**, 19-36.
- Nyssen J, Govaerts B, Araya T, Cornelis WM, Bauer H, Haile M, Sayre K, Deckers J (2010) The use of the marasha ard plough for conservation agriculture in Northern Etiopia. *Agronomy for Sustainable Development* (in press).
- Oicha T, Cornelis WM, Verplancke H, Nyssen J, Govaerts B, Behailu M, Haile M, Deckers J (2010a) Short-term effects of conservation tillage on soil (Vertisol) and crop (tef, *Eragrostis tef*) attributes in the northern Ethiopian highlands. In 'Proceedings of 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane'.
- Oicha T, Cornelis WM, Verplancke H, Nyssen J, Govaerts B, Behailu M, Haile M, Deckers J (2010b) Short-term effects of conservation tillage on Vertisols under tef (*Eragrostis tef* (Zucc.) Trotter) in the northern Ethiopian highlands. *Soil and Tillage Research* **106**, 294-302.