Field Crops Research 132 (2012) 53–62

Contents lists available at SciVerse ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Medium-term effects of conservation agriculture based cropping systems for sustainable soil and water management and crop productivity in the Ethiopian highlands

Tesfay Araya[a,b,*], Wim M. Cornelis[b], Jan Nyssen[c], Bram Govaerts[d], Fekadu Getnet[e], Hans Bauer[f], Kassa Amare[g], Dirk Raes[f], Mitiku Haile[e], Jozef Deckers[f]

[a] Mekelle University, Department of Crop and Horticultural Science, P.O. Box 231, Mekelle, Ethiopia
[b] Ghent University, Department of Soil Management, Coupure Links 653, B-9000 Gent, Belgium
[c] Ghent University, Department of Geography, Krijgslaan 281 (S8), B-9000 Gent, Belgium
[d] International Maize and Wheat Improvement Centre (CIMMYT), A.P. 6-641, Mexico D.F. 06600, Mexico
[e] Mekelle University, Department of Land Resources Management and Environmental Protection, P.O. Box 231, Mekelle, Ethiopia
[f] K.U.Leuven, Department of Earth and Environmental Sciences, Celestijnenlaan 200E, B-3001 Heverlee, Belgium
[g] Mekelle University, Department of Earth Science, P.O. Box 231, Mekelle, Ethiopia

ARTICLE INFO

Article history:
Received 12 May 2011
Received in revised form 18 November 2011
Accepted 7 December 2011

Keywords:
Conservation agriculture
Wheat
Grass pea
Crop residue
Permanent raised beds
Vertisol

ABSTRACT

In the northern Ethiopian highlands, croplands yield extremely high volumes of storm runoff and are the major contributor to sediment load in the rivers. A medium-term tillage experiment was carried out (2005–2010) on a Vertisol to quantify changes in runoff, soil loss and crop yield due to Conservation agriculture (CA) in the sub-humid May Zegzeg catchment. A randomized complete block design with 3 replications on permanent plots of 5 m by 14 m was used for three tillage treatments, (i) *derdero*+ (DER+), permanent raised beds with 30% standing crop residue retention and no-tillage on the top of the bed, (ii) *terwah*+ (TER+), ploughed once at sowing with 30% standing crop residue retention and furrows made at 1.5 m interval, and (iii) conventional tillage (CT) with a minimum of three tillage operations and removal of crop residues. Tillage operations in the three treatments were done using the local ard plough *mahresha*. Local crop rotation practices followed during the six years sequentially from the first to the sixth year included wheat-grass pea-wheat-*hanfets* (wheat and barley sown together)-grass pea-wheat. Glyphosate was sprayed starting from the third year (2007) at 2 L/ha before planting to control pre-emergent weed in DER+ and TER+. Runoff and soil loss were measured in collector trenches at the lower end of each plot. Soil organic matter was determined at two depths (0–15 cm) and (15–30 cm). Local farmers evaluated crop stands. Significantly different ($p < 0.05$) 4-yr mean soil losses of 14, 17 and 26 t/ha, 5-yr mean runoff depth of 76, 95 and 118 mm, and 5-yr runoff coefficient of 19, 24 and 30% were recorded for DER+, TER+ and CT, respectively. Soil organic matter was significantly higher in DER+ and TER+ compared to CT. The mean farmers' evaluation of crop performance in the last three years (2008–2010) showed a significant higher score for DER+ (6/8) followed by TER+ (5.6) and least for CT (4.8/8), and improvements in crop yield were observed; however, a period of at least five years of cropping was required before the difference became significant. In addition to the positive effects on runoff, soil loss and crop yield, we argue that avoiding repeated tillage which is 10–11 oxen-span days per ha and the faster ploughing pace at sowing in DER+ will enable a reduction in oxen density with further natural resource benefits. DER + and TER+ are improvements to good local practices that qualify them as CA: we recommend large scale dissemination and implementation on Vertisols.

1. Introduction

As a result of the human population growth and climate change, global agriculture will have to rely more on rainfed farming in the future. In Ethiopia, agricultural productivity is low and

* Corresponding author at: Mekelle University, Department of Crop and Horticultural Science, P.O. Box 231, Mekelle, Ethiopia. Tel.: +251 914720426; fax: +251 0344409304.
E-mail address: tesfayw2002@yahoo.com (T. Araya).

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doi:10.1016/j.fcr.2011.12.009

the sustainability of traditional agricultural systems is threatened by degradation of cropland due to complete removal of crop residues at harvest, aftermath grazing and frequent tillage in cropland (Girma, 2001; Bezuayehu et al., 2002). The main power sources in agriculture are humans and animals. Repeated tillage reduces soil organic matter and thus increases soil erosion rates by water (Angers and Mehuys, 1989; Kay, 1990; Papendick and Parr, 1997). Rainfed farming agriculture is dominant in Ethiopia and annual food production shortages are commonly linked to periodic drought and insufficient rainfall, periodical water logging and high runoff rates under wet conditions in Vertisol during the growing season (Mati, 2005; McHugh et al., 2007; Freebairn et al., 1996; Deckers et al., 2001). These problems and hence relatively low yields are associated with an imbalanced soil hydrology. The only input is rainfall (often erratic), but this rainwater is lost too much as blue water, i.e., as direct runoff, and consequently, less water is available for crops, the so-called green water (Rockström, 1997). This imbalanced soil hydrology is due to physical deterioration of the soil quality and absence of effective in situ soil and water conservation measures in the cropland itself. Therefore, in order to increase crop productivity, soil and water management practices need improvement in Ethiopia.

Some farmers in the Tigray highlands use a conventional in situ conservation tillage practice with contour furrows at 2–4 m wide intervals, locally called *terwah*, usually only on tef (*Eragrostis tef*) fields. The elongated *terwah* furrows trap and store rain water to be used later by the tef crop during dry spells instead of being lost as runoff (Gebreegziabher et al., 2009). In the Lasta highlands, south of Tigray, farmers use the *derdero* system, especially for fenugreek (*Trigonella foenum-graecum*), wheat (*Triticum* sp.) and tef on Vertisol. Beds and furrows are prepared along the contour after having broadcasted the seeds over the surface. Plants are grown on the ridges where they are protected from water logging, while draining the excess water towards the furrow where it ponds and infiltrates (Nyssen et al., 2011). In both systems, however, all straw is harvested, the stubble grazed and the furrows and beds destroyed yearly by tillage.

Although conservation agriculture (CA) is important to reduce cropland degradation and increase land productivity, it has not been implemented in northern Ethiopia beyond the achievements of the aforementioned traditional practices. Using CA can be a possible solution to lessen crop land degradation and 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. 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, this experiment was carried out in an area characterized by a subsistence farming system in a sub humid climatic condition using the local ard plough *mahresha* and local crop rotation practices in Vertisols. The modified versions of *derdero* ("*derdero* +") and *terwah* ("*terwah* +") local tillage systems using the traditional *mahresha* ard plough on Vertisol were introduced in May Zegzeg in northern Ethiopia in 2005 aiming at linking indigenous knowledge with the wide international body of knowledge on CA.

Our objective was to evaluate the effects on runoff, soil loss and crop yield of these newly developed CA versions of traditional tillage using local crop rotation systems during the six years medium term study period in sloping fields. We hypothesized that the CA based practices *derdero*+ and *terwah*+ using the local crop rotation result in reduced runoff and soil loss, and increased crop yield.

2. Materials and methods

2.1. The study area

The experiment was conducted under rainfed conditions starting from 2005 in May Zegzeg (13°39′N, 39°10′E) at an altitude of 2550 m a.s.l. in northern Ethiopia (Fig. 1). Mean annual rainfall of 26 years in the nearby town of Hagere Selam was 741 mm with more than 80% from mid June to mid September (Fig. 2), characterized by high rainfall erosivity due to large drop size (Nyssen et al., 2005). Mean monthly minimum and maximum temperatures are 4–6 °C and 20–22 °C (Nyssen et al., 2007). The average length of the growing period is 162 days (Goebel and Odenyo, 1984).

Three to four tillage operations are conventionally done with an oxen-drawn ard to control weeds, improve infiltration and prepare a fine seedbed, particularly for tef. The temporal pattern of ploughing depends on the availability of oxen, type of crop and rainfall. The most cultivated crops include tef, barley (*Hordeum vulgare*), wheat, *hanfets* (barley and wheat sown together), grass pea (*Lathyrus sativus*) and lentil (*Lens culinaris*).

2.2. Rainfall characteristics during the study period

The rainfall exceedance probability (%) and return periods for the experimental years were calculated using the RAINBOW software (Raes et al., 2006), which resulted in normal distribution of rainfall after applying a log10 transformation. The RAINBOW software was used to analyse 26 yr of rainfall data. The rainfall return periods were significantly highest ($p < 0.05$) in 2005 and 2010 as compared to the other experimental years (Table 1). To the reverse, the rainfall exceedance probability was significantly highest in 2007 (Table 1). There were longer than normal rainy seasons in 2005 and 2010, i.e., from March to September (Fig. 2). According to the local practices in the study area, grass pea planting is delayed by more than one month in the growing season as compared to the other crops to avoid excess moisture to the crop.

2.3. The field experiment

The experimental layout was a randomized complete block design with three replications (Fig. 3). The plot sizes were 5 m × 14 m and the slope was 6.5%. The soil under the experimental trial was a Vertisol with a high stone cover. Three tillage practices were applied: conventional tillage (CT), *terwah+* (TER +) and *derdero+* (DER +) all using the local ard. Following the local crop rotation practice, crops grown, from the first to the sixth year sequentially were wheat, grass pea, wheat, *hanfets* (wheat and barley sown together), grass pea and wheat. Wheat and barley were treated with the same seed and fertilizer (di-ammonium phosphate and urea) application rates at 100 kg/ha and the method of planting was by broadcasting 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 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. However, weed control in CT was done by combination of frequent tillage and hand weeding.

Terwah+ (TER +) is essentially a new tillage system developed from the traditional in situ water conservation method (*terwah*) especially used in tef where broad seedbeds are created using the *mahresha* 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, using only one ploughing operation and combined with retention of 30% standing stubble (Fig. 3). *Derdero+* (DER +) is also a newly