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Seven years resource-conserving agriculture effect on soil quality and crop productivity in the Ethiopian drylands

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ABSTRACT

Resource-conserving agriculture (RCA) aims at improving soil quality and crop yield whilst maintaining or improving soil health by minimizing soil disturbance, retaining crop residue, using crop rotations and adding *in situ* soil and water conservation tillage practices (*terwah* and *derdero*) in crop fields. In Ethiopia, intensive mining of soil resources using repeated tillage, complete crop residue removal at harvesting, overgrazing and biomass burning in croplands have aggravated soil degradation. We studied the impact of two RCA (*derdero*+ (DER+) and *terwah*+ (TER+) on long-term soil quality and crop productivity in permanently kept plots in northern Ethiopia 7 years after its inception. The two RCA practices: (i) DER+ is a bed and furrow planting system, where beds remain unploughed, furrows are tilled once at planting time and 30% of crop residue is retained. (ii) TER+ is ploughed once at planting, furrows are made at 1.5 m intervals, creating fresh broad beds, and 30% crop residue is retained. These RCA practices were compared against conventional tillage (CT) characterized by a minimum of three tillage operations and complete removal of crop residues. Among the several assessed soil properties, soil organic C (SOC), total soil N, available P, soil microbial biomass C (SMBC), time of ponding, aggregate stability index (SI), consistency index (CI), cone index, air capacity and macroporosity were shown to increase significantly in soils subjected to DER+ planting system compared to CT. On average, crop yields under DER+ and TER+ increased by 30 % and 16 %, respectively, as compared to CT. Thus, from an agro-ecological point of view, adopting improved local practices such as DER+ and TER+ planting systems that employ conservation agriculture principles proved to be sustainable, resource conserving alternatives and incentives should be provided to facilitate larger adoption by farmers in Ethiopia.

1. Introduction

In Ethiopia, conventional farming practices usually comprise intensive, repeated tillage, a complete removal of crop residues at harvest, often intensive stubble grazing, sometimes burning of crop residue, and use of straw for animal feed and animal dung for fuel. Therewith the organic matter return to the soil is limited, as is the replenishment of soil nutrients by inorganic fertilizer. Soil organic matter (SOM) has thus been steadily declining and soil erosion is widespread (Girma, 2001; Bezuayehu et al., 2002). A decrease in SOM reduces the fertility of the soil as it affects soil chemical, biological, mechanical and physical soil quality (Shukla et al., 2006). Deterioration of soil quality due to SOM depletion increases bulk density and decreases porosity, thereby reduces soil water infiltration, and water storage and air capacities (Celik, 2005).

Rainfed agriculture is dominant in Ethiopia. Continued food insecurity is commonly associated on the one hand with periodic drought and insufficient rainfall, and on the other hand with water logging and high runoff rates during the rainy season. Vertisols are

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among the most dominant soil order in Ethiopia covering 12.6 million ha and accounting for about 95% of all cultivated land in the highlands (Constable, 1984). These soils have rather unfavorable physical properties. During the rainy season, the wet topsoil causes clay swelling that leads to soil sealing, poor infiltration and water-logging.

Moreover, total N, P and K inputs to smallholder fields (with less than 1 ha) do not balance nutrient removal in the form of crop yield and animal feeds in northern Ethiopia (Abegaz et al., 2007). Consequently, N, P and K stocks in the soil are rapidly declining. In order to improve crop productivity, soil quality and *in situ* soil and water management practices need to be improved in Ethiopia.

Raised bed cultivation systems have been used for some time by farmers in many parts of the world (Sayre, 2004; Netting, 1968). The basic idea of these beds is to prevent water logging while at the same time providing for sufficient but not excessive surface water drainage. In the Tigray highlands of northern Ethiopia, farmers use a conventional *in situ* conservation tillage practice with contour furrows every 2–4 m. This practice is locally called *terwah*, in which the elongated furrows drain water but moreover serve as limited reservoir for rainwater that then can slowly infiltrate to provide for additional water instead of being lost as runoff (Araya et al., 2011). Teff (*Eragrostis tef*) is one of the main (cash) crops in the region. In the south of Tigray and adjacent regions, farmers use the *derdero* system, especially for production of fenugreek (*Trigonella foenum-graecum*), wheat (*Triticum* aestivum), lentil (*Lens culinaris*) and teff on Vertisols. In the *derdero* system, at the last tillage operation, the farmers broadcast the seeds over the surface and then prepare beds and 0.6 m spaced furrows along the contour using a local, light, small oxen-drawn ard plough (*mahresha*), moving the soil and seeds to an upper position on the beds (Nyssen et al., 2011). Similar to raised beds, this system protects the crops from water-logging, while excess water is drained thru the furrows. Excessive tillage using *mahresha* is a traditional component of both systems. Furthermore, all straw is harvested, the stubble grazed and the furrows and beds rebuilt every year.

Conservation agriculture (CA) has been widely adopted by farmers in the USA, Latin America, Europe and certain parts of South Asia to improve soil quality and crop yield (Derpsch et al., 2010). However, adoption of CA is persistently low in Sub-Saharan Africa particularly in Ethiopia (Giller et al., 2009). Resource-conserving agriculture (RCA) that integrates the principles of CA can reduce cropland degradation and improve soil quality, thereby increasing crop productivity and facilitate uptake of CA in Ethiopia. In this study, RCA systems consider the bed and furrow tillage structures of *terwah* and *derdero* as integral elements of CA. Studies on the impacts of RCA on runoff, soil loss, rainwater partitioning and crop yield from Ethiopia have been reported (Araya et al., 2011, 2015, 2016). It was shown that soil losses and runoff were significantly higher in CT systems. Yearly runoff amounted on average to 47, 71 and 98 mm for DER+, TER+ and CT, respectively, whereas annual soil loss values of respectively, 3, 11 and 17 t ha^{-1} were recorded (Araya et al., 2016). Therefore, introducing the two RCA (*terwah*+ (TER +) and *derdero*+ (DER +)) systems can be useful to improve soil quality and crop productivity by 1) minimal soil disturbance, 2) retaining crop residues on the surface, (3) using crop rotations, and (4) adding *in situ* soil and water conservation tillage practices (*terwah* and *derdero*) in crop fields. Also long-term RCA field experiments are rare in Sub-Saharan Africa. This study investigates the impacts of long-term RCA systems on soil biological, chemical, physical and mechanical properties and their consequences on crop yields in northern Ethiopia.

Therefore, this study evaluates the effects of two RCA (DER+ and TER +) systems compared to conventional tillage system on soil quality and crop yield during the seven year study period in Vertisols in semi-arid northern Ethiopia. We hypothesize that the RCA practices improve soil quality while the increased biomass production could compensate for the straw that was retained rather used as animal feed.

2. Materials and methods

2.1. The study area

The experiment was conducted under rainfed conditions from 2005 to 2011 in Adigudem (13°14′N, 39°32′E), Gumsalasa area,

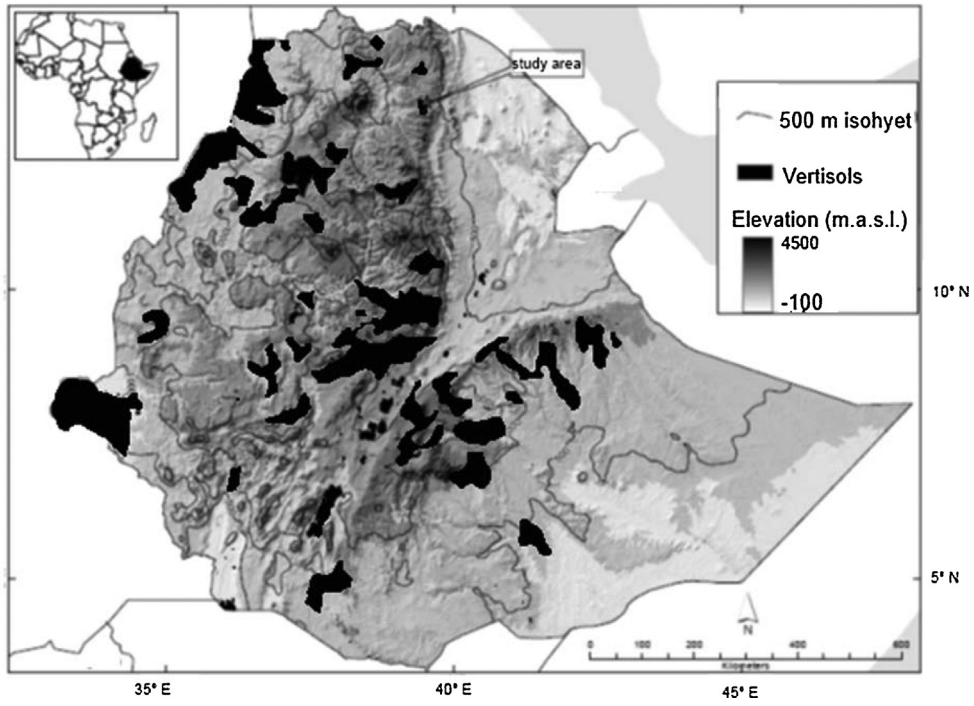

Fig. 1. Location map of the study area at Adigudem in Tigray region and FAO (1988) map for Vertisols distribution of Ethiopia.