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Review article

The use of the *marasha* ard plough for conservation agriculture in Northern Ethiopia

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Abstract – Indigenous tillage systems are often undervalued in conservation agriculture (CA). In Ethiopia, since the 1970s there have been several attempts to develop and implement often major modifications to the *marasha*, the traditional ox-drawn ard plough, with the main aim of creating various types of surface depressions. The establishment of furrows and ridges increases soil moisture and grain yield and reduces soil loss. Dissemination of the modified tools, however, remains limited. Recent tendencies are towards testing relatively simple conservation agriculture tools. Major challenges remain, however; the need for capacity building and problems in marketing the tools. From experimental plots, often worked with exotic tools, there is a long road to real adoption by farmers. Rather than developing yet another CA tool, we investigate whether CA-based resource-conserving technologies might be achieved successfully with simple changes to the use of the *marasha*. On-farm observations on traditional conservation techniques were carried out throughout the northern Ethiopian highlands, and experiments were conducted involving resource-conserving technologies. Farmers traditionally use the *marasha* ard plough for various types of in situ soil and water conservation by creating surface depressions, either at the moment of sowing (*terwah*, *derdero*) or after crop emergence (*shilshalo*). Building upon this indigenous knowledge, we further developed resource-conserving technologies into a system named *derdero*+, whereby the traditional ard plough was found suitable for a "bed-and-furrow" system. From the socio-economic point of view, implementation of permanent beds and retention of stubble leads to decreased oxen (and straw) requirements, but also to an increased need for weeding in the first years. To overcome that problem, we introduced glyphosate herbicide into the tillage system. The decreased runoff (–51%) and soil loss (–81%) allow protection of the downslope areas from flooding, but soil nutrient build-up and soil structure improvement are slow processes, and hence the full benefit of the permanent bed system can only be expected after some years. Overall, this type of resource-conserving technology can be part of the ongoing intensification process which includes physical soil and water conservation, slope reforestation and irrigation development. It has, however, its own niche: the cropped land sensu stricto, i.e. the most important part of the land, both for the farmer and for a nation that is striving for long-term food security.

animal traction / ard plough / conservation tillage / conservation agriculture / *derdero*+ / *marasha* / indigenous knowledge / permanent beds / raised beds / resource-conserving technology / soil and water conservation

Contents

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1. INTRODUCTION

In the northern Ethiopian highlands, smallholder agriculture is largely dominant and tillage takes place with a pair of oxen pulling the ard plough or *marasha* (Simoons, 1958; Nyssen et al., 2000; Solomon et al., 2006) (Fig. 1), a tool similar to that of the eastern Mediterranean and large parts of the Arab world (Audebeau and Mosséri, 1916; Varisco, 1982, 2004). The main conservation approach involves terracing by stone bunds, which is very efficient for soil and water retention within the plot. Crop yield and farmers' income increased on average by 10% (Desta et al., 2005). However, the effect of the stone bunds on crop production is concentrated along the bunds (Fig. 2) (Vancampenhout et al., 2006). Agricultural land surface management, and particularly the creation of minor closed depressions, is needed to have a conservation effect over the whole farmland. This fits into a conservation agriculture (CA) approach to enhance production, preserve natural resources and reduce poverty (Aune et al., 2001), through (a) in situ conservation of moisture, reducing runoff and evaporation; (b) reductions in erosion within farmland; (c) crop management practices that meet the above goals and increase labour efficiency and reduce the oxen requirement, leading to reductions in the demand for crop residues as livestock feed, and (d) enhanced soil fertility, to make efficient use of increased retention of rain.

Conservation agriculture (CA) is based on 3 principles (Bradford and Peterson, 2000; Verhulst et al., 2010): (1) reduction in tillage – the objective is to achieve zero tillage, but the system may involve controlled tillage seeding systems that normally do not disturb more than 20–25% of the soil surface; (2) retention of adequate levels of crop residues and surface cover on the soil surface to protect it from water and wind erosion, to reduce water runoff and evaporation, to improve water productivity and to enhance soil physical, chemical and biological properties associated with long-term sustainable productivity, and (3) use of crop rotations for the beneficial effects of some crops on soil conditions and on the productivity of subsequent crops, and to mitigate possible weed, disease and pest problems related to crop residue retention. These CA principles are applicable to a wide range of crop production systems from low-yielding, dry, rainfed conditions to high-yielding, irrigated conditions. However, the techniques to apply the principles of CA will be very different in different situations, and will vary with biophysical and system management conditions and farmer circumstances (Verhulst et al., 2010). Applying CA also means altering generations of traditional farming practices and implement use. As such, the movement towards CA-based technologies is normally comprised of a sequence of step-wise changes in cropping system management to improve productivity and sustainability, implementing resource-conserving technologies in line with the CA principles.

Particularly, bed planting provides an opportunity to reduce compaction by favouring traffic to the furrow bottoms. The next logical step to increase the sustainability of beds is to make them permanent, reducing or avoiding tillage and retaining and distributing crop residues on the surface, reshaping the beds only as needed (Sayre, 2004). Introducing permanent beds, reduced tillage and residue preservation is expected to conserve water and as such will allow sowing early and cultivating crops and varieties with a longer growing period.

In an experimental setup with conservation agriculture-based resource conservation technologies in the North Wollo region of Ethiopia, McHugh et al. (2007) found that ridges significantly increased soil moisture and grain yield and reduced soil loss, whereas no-till minimised soil loss, but reduced yield. Yet, from experimental plots, often worked with exotic tools, there is a long road to real adoption by farmers. Leeuwis and Van den Ban (2004) demonstrated that innovations in farming may only spread spontaneously when they are embedded within the local socio-economic and cultural context. Rajaram et al. (1991) further mention that indigenous tillage systems are often undervalued. Hence, rather than developing yet another CA tool, we investigate here whether CA-based resource-conserving technologies might be achieved successfully with simple changes to the use of the *marasha*. Simplicity is a key concept for CA-based resource-conserving technologies. Hence our working hypothesis has been that further adaptations of the *marasha* can and will be made, but wholesale changes are probably unnecessary to the ox-drawn implement. After all, the farmers of Ethiopia have been adjusting this tool for thousands of years so as to meet their requirements under Ethiopian soil conditions.

We have chosen a step-by-step, empirical approach that involves intimate farmer participation throughout the initial research on possible strategies/technologies, the testing and modification of the most relevant possibilities, and finally, the extension of the final products.

2. TILLAGE IN THE AGRICULTURAL SYSTEM OF THE NORTHERN ETHIOPIAN HIGHLANDS

The tropical highlands of Ethiopia are densely populated and have been cropped intensively for centuries (Nyssen et al., 2004). Agricultural sustainability problems related to soil erosion and fertility decline have arisen throughout this agro-ecological zone. The agricultural system is under stress due to the shrinking cultivated area per household, reduced fodder availability and land degradation (Aune et al., 2001).

This study concerns the Tigray and northern Amhara (Lasta) regions in the northern Ethiopian highlands (Fig. 3). The main rainy season (>80% of total rainfall) extends from June to September but is sometimes preceded by three months of dispersed less intense rains. Average yearly precipitation is 500–800 mm. Agriculture in the northern Ethiopian highlands consists exclusively of smallholder farming activities, with landholdings approximately equal in size. Each household crops two or three parcels of land, with a combined area of between 0.5 and 1 ha (Nyssen et al., 2008). The agricultural system in the northern Ethiopian highlands has been characterised as a "grain-plough complex" with annually cropped fields. The main crops are barley (*Hordeum vulgare*), wheat (*Triticum* sp.), sorghum (*Sorghum bicolor*), maize (*Zea mays*) and tef (*Eragrostis tef*), an endemic cereal crop. Different species of

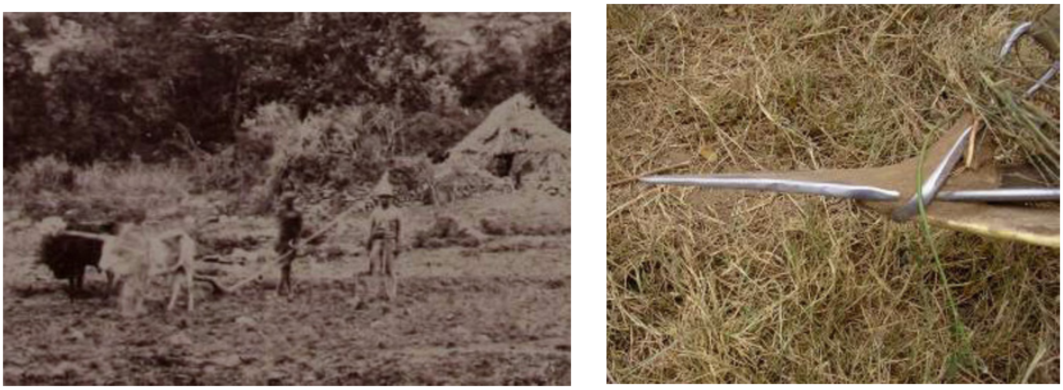

Figure 1. The first ever photograph of an Ethiopian farmer with his oxen and *marasha*, near Senkata (Tigray) in March 1868 (© Royal Engineers of the British Army, reprinted with permission of the King's Own Museum, Lancaster, UK) and detail of the metal tine with wooden "ears" (Photo Leigh Vial).

Figure 2. A sorghum and maize farm in the May Zegzeg catchment, Tigray, October 2005. The implementation of stone bunds for soil and water conservation has led to strongly improved yields in the vicinity of the bunds (arrow shows strong maize growth). In the foreground, *terwah* furrows remain visible in the harvested land.

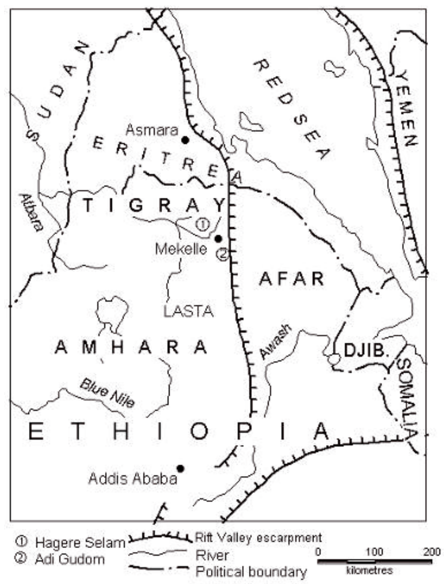

Figure 3. The target area.

pulses are also an important part of the crop rotation (Nyssen et al., 2008). As rainfall is inadequate and unpredictable, crop production is threatened by chronic soil moisture stress. Precipitation is often intense, leading to high runoff and temporary waterlogging. Cereal grain yields are low (<2 t ha^{-1}). Moreover, crops are often weedy and nitrogen-deficient, soil structure is poor, and soil erosion is widespread (Tadesse et al., 1996; Asefa et al., 2004; Spaccini et al., 2006; Nyssen et al., 2008).

Soil tillage with the *marasha* is commonly used to prepare flat seedbeds. The tool, pulled by a pair of oxen, breaks, but does not turn, the soil to provide weed-free seedbeds at sowing and to enhance infiltration (Melesse et al., 2008). The farmers adjust the tillage depth by modifying the length of the ploughshare and its angle and by the downward pressure on the handle. The amount of land a pair of oxen can plough in one day varies with oxen strength and with soil type and is estimated at about 0.25 ha day^{-1}. Multiple tillage operations are carried out in order to prepare a fine seedbed, particularly for tef, with 3–5 operations. This leads to poor physical soil properties, as expressed by very hard topsoils and difficult tillage conditions when the next crop needs to be sown. After harvesting, stubble grazing is widespread, followed by several tillage operations.

Oxen are of vital importance for assuring livelihood security as they can be sold when the household experiences a stress situation such as drought. There is also a high social prestige associated with ox ownership (Aune et al., 2001). The productivity of the Ethiopian livestock system is declining as an increasing part of the biomass resources are consumed by oxen and other livestock. A change in the livestock population and productivity will not occur unless the tillage system is modified and overall crop productivity improved.

Two sites, both on Vertisols, were selected for experimental studies on land preparation techniques (Fig. 3): (1) the May Zegzeg catchment near Hagere Selam (2600 m a.s.l.), where catchment management including zero grazing has been implemented since January 2004 (Nyssen et al., 2009) and (2) the

Figure 4. Italian mouldboard ploughs imported into Ethiopia (near Mekelle, in 1938, photo Guidotti). "Gift of H.E. the Head of State to the inhabitants of Tigray" states the original legend of this photograph obtained from the Istituto Agronomico per l'Oltremare (Florence, Italy). As for other, more recent metal tools, the technology was not adopted by the Ethiopian smallholder farmers, especially due to excessive draught requirements and problems in maintenance.

Gum Salasa area near Adi Gudom (2090 m a.s.l.) (Tewodros et al., 2009; Tesfay et al., 2010; Tigist et al., 2010). Vertisols are challenging for land preparation: they are very hard when dry, and in the rainy season, when their upper part gets moistened, clay swelling leads to soil sealing, poor infiltration and waterlogging. Due to its resistance to waterlogging, tef is a preferred crop on this soil type, but the repeated ploughing that is done to prepare its fine seedbed leads to collapse of the soil structure and hence leaves behind a compacted topsoil.

3. INTRODUCTION OF IMPLEMENTS

In the past, researchers and organisations repeatedly attempted to replace or modify the *marasha* plough, for CA operations among others. The typical trajectory of adoption is similar to that of the steel mouldboard ploughs introduced by the Italians in the 1930s (Fig. 4). This was unsuccessful at smallholder level due to its heavy weight, the need for complicated adjustments and the higher power requirements than those of the Ethiopian ard, especially in soils with high clay contents (Solomon et al., 2006). Since the 1970s there have been several attempts to develop and implement a broad bed and furrow maker in Ethiopia (Jutzi et al., 1987). However, like other implements, dissemination of broad bed makers was very limited (Solomon et al., 2006). Recent tendencies are towards testing relatively simple CA-based resource-conserving technology tools (Melesse et al., 2009). Major challenges remain, however; the need for capacity building and problems in marketing the tools (Rockström et al., 2009).

On the other hand, research on the raised bed and furrow making in central Ethiopia mainly focused on draining excess water for the optimum production in Vertisol-dominated areas where soil water is generally not a limiting factor (Abiye et al., 2002).

As preparing beds and furrows with hand tools is not an option, except sometimes in irrigated land, our research has been oriented towards the use of the non-modified *marasha* for land preparation in a raised-bed CA-based resource conservation system.

4. INDIGENOUS USE OF THE *MARASHA* FOR IN SITU SOIL AND WATER CONSERVATION

On-farm observations were carried out at various locations throughout the Tigray and Lasta highlands, and interviews with farmers and agricultural extension workers allowed characterising the prevailing in situ soil and water conservation techniques using the *marasha*: *shilshalo*, *terwah* and *derdero* (Tab. I).

4.1. The *terwah* technique

The *terwah* technique, a traditional tillage system (Tab. I; Fig. 2), is especially used in tef, where the farmers prepare furrows on the contour at regular intervals (approx. 1.5 m) to conserve water. This technique differs from the guide furrows which one can see in many fields, by the fact that (1) the furrows are deeper and wider, and (2) the *marasha* is adjusted to prepare these furrows, whereby specially prepared *doogri* (wings) are fitted on it. As a consequence, part of the runoff is trapped in the *terwah* and allowed to infiltrate. At these places the crop will grow particularly well. This technique is applied especially in tef, because this crop is sown on the surface after seedbed preparation without more ploughing (Deckers et al., 2001), allowing the farmer to also sow inside the *terwah*, which avoids the perception that the *terwah* is occupying valuable land. Using the *terwah* system for CA-based resource-conserving technologies with other crops than tef exists as a concept in Ethiopia but meets resistance. A senior agricultural officer in Tigray explained that agricultural experts prefer to focus on complicated implements such as the tied ridger while neglecting traditional techniques.

The *terwah* technique differs from *michdad* or *feses*, which are graded furrows to evacuate excess water from waterlogged areas or from whole farm fields (Erkossa et al., 2005), especially in high rainfall areas where it may lead to rill erosion (Woldeamlak and Sterk, 2003). However, in most of northern Ethiopia, moisture is an important limiting factor for agricultural production, hence in situ moisture retention

Table I. Overview of traditional in situ soil and water conservation in Ethiopia and modified conservation agriculture-based resource-conserving technologies, all using the *marasha*.

	Moment of implementation	Tillage system	
		Broad-spaced, deeper furrows on contour	Narrow-spaced, deeper furrows on contour
Traditional in situ conservation tillage	Yearly, after emergence		*Shilshalo* (on sorghum and maize only) (Sect. 4.2; Fig. 5)
	Yearly, at last tillage (at sowing)	*Terwah* (on tef only) (Sect. 4.1; Fig. 2)	*Derdero* (on all crops) (Sect. 4.3; Fig. 6)
Modified resource-conserving tillage	Yearly, at last tillage (at sowing)	*Terwah*, retaining stubble (on all crops) (5.3; Fig. 9)	Semi-permanent beds = *derdero,* retaining stubble (5.2; Fig. 8)
	Permanent; yearly, refreshed at sowing		*Derdero*+ = permanent beds, retaining stubble and using non-selective herbicides (before furrow refreshment and sowing) (5.1; Fig. 7)

is important. The improvement in crop performance in the vicinity of the bunds and terraces constructed along the contour (Vancampenhout et al., 2006) is a good indicator for the need to make contour furrows in the farm fields. An experimental site equipped with lined runoff and sediment collectors (Tewodros et al., 2009; Tesfay et al., 2010; Tigist et al., 2010) was used in 2005, 2006 and 2007 to compare the practice of ploughing and broadcast sowing on plain seedbeds with the *terwah* system, among other things. Here, the technique was shown to be effective for in situ soil and water conservation, reducing runoff on average by 11% and soil loss by 36% (Tab. II). An important result of these runoff plot measurements, however, is that the *terwah* technique is efficient especially at the beginning of the rainy season (when soil moisture is most needed by the plants), whereas during the second part of the rainy season the furrows get filled with sediment; the land behaves from then onwards in a similar way to the plain tilled land (Tewodros et al., 2009).

Currently, the *terwah* method is promoted by the Agricultural Office extension services, who additionally advise lifting the plough from time to time (every 4 or 5 m) when preparing the *terwah*. In this way, the furrow is interrupted like a tied ridge; hence lateral drainage is avoided or slowed down.

4.2. *Shilshalo*

Throughout Ethiopia, when farmers grow sorghum or maize, they use the *marasha* to create contour furrows within the standing crop during the (second) weeding operation (Gebreyesus et al., 2006). The technique has also been documented in Yemen (Bédoucha, 1986; Varisco, 2004). Besides weeding and plant thinning, the aim of the practice (*miguemas* in Tigrinya, *shilshalo* in Amharic and south Tigray; Tab. I) is to enhance runoff capture, particularly in semi-arid areas. In our target area, and despite the existence of very heavy rains in August when *shilshalo* is practised (Nyssen et al., 2005), the furrows are made along the contour and are slightly curved upwards at both ends of the farmland to enhance the water harvesting effect. In addition, plant physiologists have pointed to the sorghum crop root pruning that takes place and which enhances root growth (Blum et al., 1977; Rajaram et al., 1991; Blum, 2004).

Figure 5. *Shilshalo* ploughing as practised on sorghum, some weeks after emergence in the May Zegzeg catchment. In one tillage operation, weeding, thinning and root pruning is done; the furrows also decrease runoff and enhance infiltration.

In May Zegzeg, except in three farm fields, *shilshalo* was practised by all farmers who planted sorghum (Fig. 5). A comparison of crop yields sampled on 4-m^2 plots in these three farmers' fields yielded no significant difference with 14 randomly selected farm plots where *shilshalo* was applied: 0.86 (±0.34) t ha^{-1} grain on plots with *shilshalo* against 0.90 (±0.56) t ha^{-1} without *shilshalo.* Yet, all farmers in that area claim that without implementing *shilshalo* one can hardly grow sorghum.

Gebreyesus et al. (2006) obtained on an experimental plot in Avergelle, 100 km away, but lower, warmer and less rainy, mean sorghum yields of 1.78 t ha^{-1} for *shilshalo* and 1.48 t ha^{-1} for crops where no furrows were created after plant emergence (results of two years on an experimental plot with three replicates). This tends to indicate that the *shilshalo* practice is especially essential for sorghum production in rain-deficit areas. McHugh et al. (2007) also mention the indigenous practice of *shilshalo* which is practised by many farmers in Wello on their sorghum crops for the sake of moisture conservation. Tilahun et al. (2002) further recommended

Table II. Runoff and soil loss (July–September) from farmland on Vertisols treated with *derdero+* and *terwah* ploughing (both without herbicide) as compared with traditional management.

Site	Year	*n*	Runoff											Soil loss								Source
			Conventional			*Derdero+*				*Terwah*				Conventional		*Derdero+*			*Terwah*			
			m^3 ha^{-1}	s.d.	RC	m^3 ha^{-1}	s.d.	RC	%	m^3 ha^{-1}	s.d.	RC	%	t ha^{-1}	s.d.	t ha^{-1}	s.d.	%	t ha^{-1}	s.d.	%	
Gum Selasa	2005	2	647		0.15	255		0.06	40	377		0.09	60	19.5		4.6		23	7.6		39	(Tewodros et al., 2009)
Gum Selasa	2006	2	928	152	0.27	467	104	0.13	50	782	60	0.22	81	9.7	2.3	1.4	0.3	14	4.6	1.6	47	(Tigist et al., 2010)
Gum Selasa	2007	2	1158	224	0.27	650	444	0.15	56	1366	229	0.32	118		–	–	–	–	–	–	–	(Tesfay et al., 2010)
May Zegzeg	2005	3	1620		0.16	1496		0.14	92	1592		0.15	98	10.4		8.2		78	11.0		107	(Fekadu, 2006)
May Zegzeg	2007	3	1311	149	0.35	920	126	0.24	70	1129	326	0.30	86		–	–	–	–	–	–	–	(Own data)
Average			1133		0.24	758		0.14	62	1049		0.22	89	13.2		4.7		38	7.7		64	

RC = runoff coefficient; s.d. = standard deviation; % = results of *terwah* and *derdero+* treatment expressed in percent of the conventional tillage.

Figure 6. The indigenous *derdero* technique applied on a farmer's field with fenugreek near Densa (Lasta), August 2007. Book for scale. Tillage after sowing has created the typical bed-and-furrow topography and brought most of the seeds to the beds.

sowing an intercropped legume at the moment of *shilshalo*. Some authors, however, merely recognise *shilshalo* as a weeding technique (Rezene et al., 1992; Hussein et al., 2000). While identifying the *shilshalo* technique, Sasakawa Global 2000 abandoned it on its CA experimental plots with maize, replacing it by glyphosate spraying (Ito et al., 2007).

4.3. *Derdero*

In Lasta, the *derdero* system is applied by many farmers, especially for fenugreek (*Trigonella foenum-graecum*), wheat and tef. At the last tillage operation, the farmer broadcasts the seeds over the surface, and then prepares beds and furrows along the contour using the *marasha*, in order to conserve water (Tab. I). Soil and seeds that are on the position of the furrows are moved to an upper position on the beds in the ploughing process. Most of the plants will then germinate on the beds (Fig. 6). The *derdero* technique is especially used on Vertisols: in rain-rich locations or rain-rich years, it allows one to have the plants grouped in a slightly higher position on the ridges, i.e. protected from waterlogging, while the excess water is drained towards the furrows where it ponds and slowly infiltrates.

Whereas *shilshalo* is applied after emergence (particularly of sorghum and maize), *derdero* tillage is done at sowing time, so that surface depressions exist from the date of sowing onwards.

This tillage system shows many similarities to the "corrugaciones" tillage system in wheat-growing areas in North America. Farmers sow the field, incorporate the seed with a last ploughing operation and subsequently make furrows. In recent years, the "corrugaciones" are frequently used in rainfed systems, where the furrows either serve to drain excess water of heavy rain showers, or to avoid runoff, and as such enhance the water harvest capacity of the field in semi-arid areas (Medina et al., 2003). A similar tillage system has been reported in Yemen (Behnstedt, 1987; Varisco, 2004).

5. BED-AND-FURROWS FOR THE NORTHERN ETHIOPIAN HIGHLANDS

Having noted the appropriateness of the *marasha* for surface shaping for conservation, such as *terwah*, *shilshalo* and *derdero*, the next logical step was then to link the tool up with the wide international body of knowledge on CA (Wall, 2007). Through discussion, empirical design, formal experiments and promotion of on-farm use, our current concept of CA and CA-based resource-conserving technologies for smallholder farmers in the north Ethiopian highlands came to include the following:

- limited tillage activity, to enhance soil structure and to decrease the cost of maintaining oxen;
- use of *marasha* as a tool for CA-based resource-conserving technologies;
- leaving half the straw length as standing stubble after harvest;
- crop rotation;
- critical use of non-selective herbicide just before sowing; and
- abandonment of stubble grazing (to improve soil fertility, to decrease compaction and to avoid browsing of standing stubble as well as roaming livestock just after spraying of herbicide).

This newly developed tillage system is called *derdero+*, where the "plus" stands for the improvements made. The basic system that has been developed consists of permanent beds with standing stubble (5.1 in Tab. I). Here, parallel furrows are made on the contour at intervals of approx. 60 cm, using half the width of the yoke as a measurement (Fig. 7). In the first year of implementation, the furrows are refreshed a few times during the period of land preparation. At sowing, crops are broadcast over the land, and the furrows reshaped, whereby the soil is moved to the beds, thereby covering the seed. In subsequent years, one single tillage pass at the moment of broadcast sowing allows a refreshment of the furrow, reshaping of the bed and covering of seeds at the same time (Fig. 7).

The *derdero+* land preparation system (Figs. 7 and 8), in which the farmer needs to adjust his *marasha* in such a way that the sediment uplifted from the furrows is well spread over the beds, has proven to work with wheat (Tesfay et al., 2010), barley, chickpea, maize and grasspea. For tef, the implementation is slightly different: on the day of sowing, the furrows are first refreshed by *marasha*, whereafter the seed is sown over the surface, including beds and furrows. The traditional incorporation of the seeds into the top 1 cm is done using thorny *Acacia* sp. branches.

Results from our experimental sites show that this system leads to an average decrease in runoff of 38% and in soil loss of 62% (Tab. II).

6. FUTURE OF THE *DERDERO*+ SYSTEM

One particular problem that had to be overcome was weed infestation, as frequent tillage no longer takes place: at the

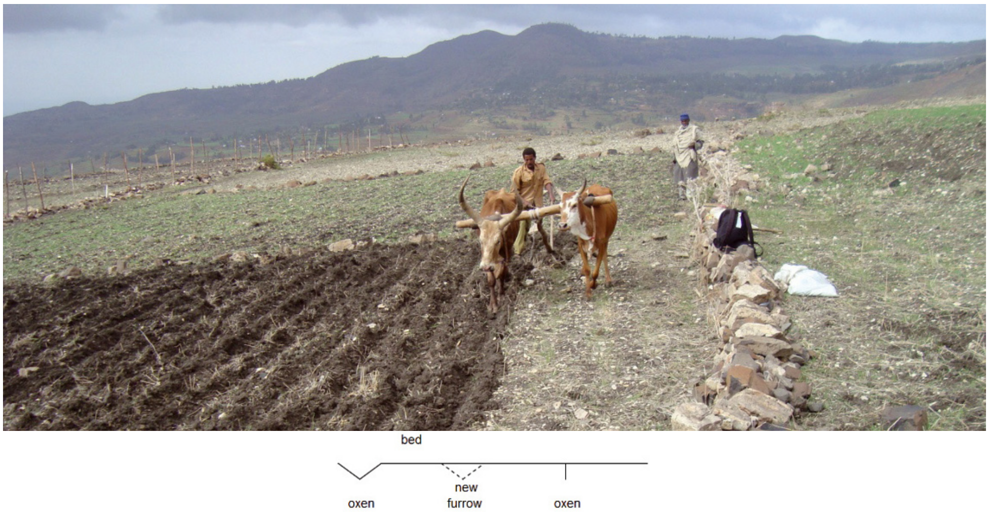

Figure 7. The *derdero*+ system involves shaping of beds and furrows by a pair of draught animals with attached *marasha* (on a farmer's field in May Zegzeg, July 2009). Only a single, broad-spaced tillage operation is needed. The farmer replaced one of the oxen in the span by a (weak) cow, as only the 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.

Figure 8. Wheat on permanent beds (*derdero*+ system) in a farmer's field in May Zegzeg, August 2007. Beds were reshaped in a single tillage operation immediately after broadcast sowing.

beginning of our experimentation, there were large invasions of *Cynodon dactylon*, which could not be controlled by hand weeding and which particularly affected tef growth (Tigist et al., 2010) (Fig. 9).

We have recently introduced the use of glyphosate herbicide on the permanent beds, a few days before sowing, when maximum emergence of the seed bank has taken place. There is a good rationale for the use of herbicides, since tillage operations are carried out only by men and weeding is done mostly by women and children. Hence the introduction of *derdero*+ without use of herbicides would have led to significant shifts in workload from men to women and children. However, follow-up of appropriate use and dosing of the herbicide is of utmost importance (Christoffoleti et al., 2008). The constraints related to herbicide weed control are related to the fact that spraying is a knowledge-intensive technology. Hence, the extension of CA-based resource-conserving technologies needs to be combined with innovation systems that support training and knowledge transfers. As used to be the case in Ethiopia for fertiliser not so long ago, there is no structure/system in place at the moment for such inputs. Our working example is deemed to catalyse the innovation network and make the needed change to input and output markets.

Two intermediate systems were also introduced, which can be very useful for farmers who hesitate to use herbicide or who believe that "a good farmer ploughs his land many times" (Melesse et al., 2008). Firstly, to manage semi-permanent beds we apply the *derdero* technique, whereby in addition we keep standing stubble on the land (5.2 in Tab. I). After several normal tillage operations, without herbicide application, the land will be shaped into contour beds and furrows immediately after broadcast sowing and beds and furrows remain throughout the crop-growing period. The second intermediate system consists of *terwah* ploughing for all crops, as promoted by the Bureau of Agriculture (5.3 in Tab. I); traditionally it used only to be done for tef (Fig. 10).

At this initial stage of implementation, our agronomic results for permanent beds do not show a significant difference in crop and straw yield with traditional tillage. We measured a slight increase in wheat yield (Tewodros et al., 2009; Tesfay et al., 2010) and a decrease in tef yield (Tigist et al., 2010) (Fig. 9), which was most probably related to the earlier mentioned weed problems in the absence of herbicide use. Further increase is expected to occur in the future, when the weed

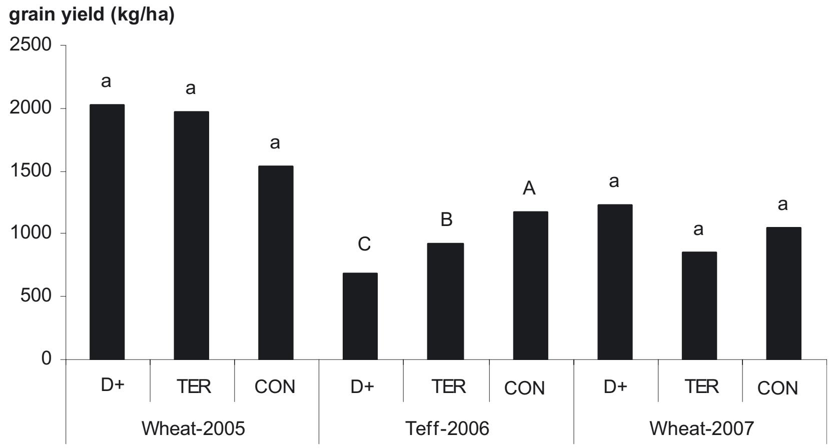

Figure 9. Average grain yield (kg/ha) trend in conservation and conventional agriculture in Gum Selasa. Different letters stand for significant difference ($P < 0.05$) between treatments per year. D+ = *derdero*+ (without use of herbicide), TER= *terwah*, CON = conventional tillage (after Tesfay et al., 2010).

Figure 10. The stripped pattern of this wheat farm at the ripening stage in May Mereb (5 km west of Hagere Selam; October 2005) is due to enhanced soil moisture in the area around *terwah* furrows (see detail in Fig. 2). Traditionally, *terwah* ploughing is only used with tef, but in recent years the local Bureau of Agriculture has promoted the establishment of such broad-spaced deeper furrows at sowing time of other crops as well.

seed bank becomes exhausted and soil physical and chemical properties improve. Obviously, for the same crop yield, labour investment and draught force requirement are strongly reduced with *derdero*+, with only one tillage pass that consists of simply refreshing furrows (Fig. 7). The use of cows and donkeys for tillage becomes possible. Similar to our case, Wall (2007) found that in many developing countries, one of the most important benefits of CA for smallholder farmers is the reduction in labour requirements, both by oxen and humans, for tillage. However, if only manual weeding is practised, then labour requirements may increase, making the system unattractive to farmers (Muliokela et al., 2001). Hence the use of glyphosate in our *derdero*+ CA system.

The abandonment of stubble grazing, which has definite advantages in terms of soil conservation (Nyssen et al., 2009), is a prerequisite for implementation of resource-conserving technologies. The issue of leaving standing stubble fits in the same paradigm as the establishment of exclosures (Descheemaeker et al., 2006; Wolde et al., 2007), where previously overgrazed rangeland has been left to regrow and fodder is taken through cut and carry. The only way to get out of the vicious circle of land degradation caused by overgrazing is to increase total biomass production per land unit, so that one can cut and carry part of the straw and leave part for system sustainability. The aimed-for increase in productivity would allow both harvesting the upper part of the straw and leaving tall standing stubble. Zero grazing is promoted in the target area but meets with resistance as there is a strong tradition of off-season grazing. In May Zegzeg, where free grazing has been abolished, the developed *derdero*+ technology has been implemented on ten farmers' fields (Fig. 9) 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. 7). Farmers in that area also claim that in the absence of compaction by livestock hoofs and with reduced tillage, the topsoil has become particularly soft.

To enhance area-wide adoption, we agree with Ekboir (2002), who stated that although the development of no-till packages and their adoption by small-scale farmers followed different paths than for large-scale farmers, the paths shared one important common feature: all successful programmes resulted from networks that worked with participatory research approaches. Wall (2007) further stresses the need for interested agents to catalyse innovation systems and, based on the activities of innovative farmers, to help overcome problems observed in farmer experiments. These highly participatory innovation systems do not develop without a catalyst: an individual or organisation with a specific interest in advancing the technology and its adoption (Wall, 2007).

7. CONCLUSIONS

Research on CA and CA-based resource-conserving technologies in Ethiopia generally fits into two major paradigms: (1) flat seedbed with use of herbicide and one surficial tillage operation (Ito et al., 2007); or (2) surface shaping using various (often heavy and complex) tools (Hussein et al., 2000; Abiye et al., 2002; Gebreyesus et al., 2006; McHugh et al., 2007; and many others). In both cases, indigenous in situ soil and water conservation tillage technology, if recognised, is merely mentioned anecdotally (Gebreyesus et al., 2006; McHugh et al., 2007), and even considered as an interference with the experiment (Hussein et al., 2000; Ito et al., 2007).

Yet, in the northern Ethiopian highlands farmers traditionally use the *marasha* ard plough for in situ conservation by creating surface depressions, either at the moment of sowing (*terwah*, *derdero*) or after crop emergence (*shilshalo*). On Vertisols, the indigenous conservation technologies *terwah* and *derdero* aim to locally drain out the crops while curbing runoff and favouring infiltration.

Building upon this indigenous knowledge, we further developed CA-based resource-conserving technologies into *derdero*+ whereby the traditional ard plough was found suitable for a 'bed-and-furrow' system. The concept further integrates the retention of stubble, improving the soil structure by decreasing the number of tillage operations, whereby tillage becomes limited to transferring sediment from the furrows to the beds at the moment of sowing.

From the socio-economic point of view, implementation of permanent beds leads to decreased oxen (and hence straw) requirements, but also to increased need for weeding in the first years unless herbicide is used. These modified labour requirements need to be studied. The commonly practised stubble grazing system is incompatible with stubble management that is part of *derdero*+. It is expected that benefits from *derdero*+ will be an additional incentive for free grazing abandonment.

Furthermore, the decreased runoff (–51%) and soil loss (–81%) allow protection of the downslope areas from flooding, but soil nutrient build-up and soil structure improvement are slow processes, and hence the full benefit of the permanent bed system can only be expected after some years.

Overall, *derdero*+ can be part of the ongoing intensification process which includes physical soil and water conservation, slope reforestation and irrigation development, and will have to be implemented through a step-by-step process of adoption of resource-conserving technologies that lead to CA. It has its own niche: the cropped land sensu stricto, i.e. the most important part of the land, both for the farmer and for a nation that is striving for food security. Hence, it is suggested that the permanent bed *derdero*+ system could be widely implemented on farmers' fields after several years of experimentation, when stable improved crop yields can be shown. The *terwah* system is a very good first step, resulting in decreased runoff (–11%) and soil loss (–36%), and we strongly recommend implementing it on all farmland in northern Ethiopia. However, the long-term goal is to achieve a permanent bed planting system.

In a country like Ethiopia, with an enabling environment for smallholder agriculture (Mitiku et al., 2006) and with the *marasha* as a tool that is almost ready for use, there are good prospects for CA and bed-and-furrow CA-based resource-conserving technologies.

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