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Full Length Research Paper

Conservation tillage implementation under rainfed agriculture: Implication for soil fertility, green water management, soil loss and grain yield in the Ethiopian Highlands

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Soil degradation and declining agricultural productivity due to soil erosion and poor soil management using repeated cross plowing by the traditional plow had been the major problem in the Ethiopian highlands. To reduce the impacts of land degradation, research institutes, researchers and NGOs cooperatively developed and or adopted conservation tillage tools and had been implemented in an on-farm experiment for the last decades. Thus, this paper reviewed scientific conservation tillage researches which had been conducted on its impact on soil fertility, soil water properties, runoff, soil loss and agricultural productivity in the Ethiopian highlands. Majority of the implemented conservation tillage had brought significant effect on soil fertility improvement, moisture conservation, increased yield, reduced runoff and soil loss compared to the traditional tillage. Although, tillage changes soil properties, the effects had been usually inconsistent and not repeatable from site to site and time to time. Environmental and socio-economic factors especially weed infestations and unaffordable costs are among the major challenges for its adoption in Ethiopia. To optimize the productivity and maintain the sustainability of soils, further studies on the effect of long-term tillage particularly on soils and soil water properties under various tillage practices and environments would be essential.

Key words: Conservation tillage, grain yield, soil loss, infiltration, runoff, soil moisture, Ethiopia.

INTRODUCTION

Tillage is the mechanical manipulations of soil to keep it lose for plant growth and free from weed during the growth of plant (FAO, 1993). The fundamental purposes of tillage include preparing suitable seed bed for plant growth, destroying competitive weed and improving the physical condition of soil (Rockström, 2000). Conservation Tillage (CT) refers to reduced-tillage cropping systems including no-tillage, strip tillage, minimum till, stubble mulch farming, mulch tillage and ridge tillage (ECAF, 1999). CT is technically defined as a cropping system where at least 30% or more of the soil surface covered with crop residue following tillage and planting (Rockstrom et al., 2003b). These residues protect the soil from erosion, wind and water. The operating principle behind conservation tillage is to minimize the disturbance of the soil (Benites and Ashburner, 2001). Conservation tillage (CT) has become an important management tool in production systems throughout the world. The term "conservation tillage" has been defined in various ways over the past 70 years, depending on the region in which it has been practiced (Temesgen, 2007). It is designed to reduce erosion and maintain or improve soil health properties, increases infiltration by reducing surface sealing and enhancing macro pore connectivity and flow (Temesgen et al., 2007).

Conservation tillage systems are gaining increased attention as a way to reduce the water footprint of crops by improving soil water infiltration, increasing soil moisture and reducing runoff and water contamination (Abegaz, 2005; Gebremchael et al., 2006; Lal, 2000; Lal, 1995; Lal, 1989). At the same time, several studies have demonstrated that these systems can improve soil quality, reduce erosion and compaction, increase grain yield, soil organic matter and moderate soil temperatures (Descheemaeker et al., 2006; Lal, 1993; Nyssen et al., 2011).

In countries where agriculture is rain-fed, subsistence and the main economic activity like Ethiopia, moisture conservation and increase water productivity through the application of conservation tillage is paramount important (Biamah and Rockstrom, 2000; Oicha et al., 2010; Temesgen et al., 2007; Lal, 1995; Lal, 1993). Food security in Ethiopia is strongly dependent on rainfall variability and soil management practices. The major challenge for the rural communities, representing up to 80 % of the population in the country, is to improve the productivity of rainwater and the available natural resources (Atlabachew, 2006; Descheemaeker et al., 2006;Hurni et al., 2005). Results of on-farm experiments during three cropping seasons demonstrated that conservation tillage can be beneficial for improving soil moisture, raising grain yields and reducing runoff and soil loss in the northern Ethiopian highlands (McHugh et al., 2007; Mesfine et al., 2005).

In the semi-arid regions of Sub-Saharan Africa including Ethiopia, short intense storms coupled with prolonged dry spells and poor soil management systems make crop production difficult (Rockstrom, 2000; Rockstrom, 1997). Intensive rainfall causes a high proportion of surface runoff that also carries away the top of fertile soil. Due to high temperature, soil evaporation can reach 30-50% of the total rainfall leaving only 10-30% for crop transpiration (Rockstrom, 2003a; Rockstrom, 1999). Furthermore, primary production is low because of the highly variable rainfall, high evaporation rates, high surface runoff and long drought periods (Abdulkedir and Richard, 2005). Poor rainfall partitioning leads to low water productivity (Temesgen et al., 2007; Rockstrom, 1999). Thus, considering the wider application of conservation tillage among the resources poor farmers is crucial, since proper soil management enhances rainwater infiltration and water holding capacity of the soil thereby minimizing evaporation losses especially during the dry periods.

More than 80% of Ethiopia's population is involved in agriculture and crop production; mostly occurs under rain-fed conditions, most of which is marginalized by moisture stress (Atlabachew, 2006; Temesgen et al., 2009; McHugh, 2006). Haregeweyn et al., (2005) also concluded that moisture stress is the limiting factor for the productivity of rainfed agriculture in the semi-arid regions of northern Ethiopia. In addition to this, tillage in Ethiopia is carried out with a breaking ard plough, locally known as "*maresha*", whose shape and structure have remained unchanged for thousands of years (McHugh, 2006; Nyssen et al., 2000; Temesgen et al., 2012). Soil erosion due to high tillage frequency has seriously affected the Ethiopian highlands (Chuma, 1993; Gebremchael et al., 2006). Many researchers point out that, soil management practices are the critical problems in the highlands of Ethiopia where most of the food insecure populations live (Bewket, 2003; Gebremichael et al., 2006; Gebretsadik et al., 2009; Nyssen et al, 2009). This has greatly influenced the sustainability of crop production in most part of the country.

In Ethiopia, repeated cross plowing, complete removal of crop residues at harvest, aftermath grazing of crop fields and occurrence of repeated droughts have reduced the biomass return to the soil and aggravated cropland degradation (Araya et al., 2014). Cross-plowing is practiced because the traditional ard plow in Ethiopia, called *Maresha*, cannot be efficiently used over the same line of plowing in consecutive tillage operations (Temesgen et al., 2008). Therefore, any two consecutive tillage operations have to be carried out perpendicular to each other, which is called cross-plowing. Cross plowing increases surface runoff as a result of plowing up and down the slope, which has also been demonstrated elsewhere (Rowland, 1993). Increased surface runoff leads to either detention of too much water at the bunds leading to water logging or breaching of the bunds leading to accelerated soil erosion downstream.

One way of tackling the problem of breakdowns of bunds is to reduce the surface runoff reaching the structures by introducing conservation farming. Conservation agriculture (CA) was introduced as a concept for resource-efficient agricultural crop production based on an integrated management of soil, water and biological resources combined with external inputs (FAO, 2008). This resource conserving cropping systems may reduce runoff and soil erosion and improve soil quality, thereby increasing crop productivity (Araya et al., 2014). Nowadays, to reduce soil erosion, nutrient losses, surface runoff, increased green water availability and grain yield, different farmers and researchers had been implemented conservation tillage systems in many parts of the Ethiopian highlands. Thus, this paper reviewed the impact of conservation tillage systems on soil fertility, surface runoff, moisture, soil loss and grain yield in the highland of Ethiopia.

The Effect of Conservation Tillage on Selected Soil Physico-Chemical Properties

Soil Physical Property

Soil quality deterioration and consequent reduced productivity characterize the Vertisols in the highlands of Ethiopia (Taa et al., 2005). Soil quality can be determined by quantifying the physical, chemical and biological parameters that has a major impact on agricultural productivity and sustainability (Erkosa et al., 2011; Erkosa, 2006). Tillage practice had greater bearing on the soil physical properties, which in turn influence soil-water relations. Kidane et al. (2012) reported that plots treated with the modified *Maresha* called (winged subsoiler) had relatively low bulk density compared to traditional tillage (TT). This can be attributed to the break-down of compacted soil and improved porosity at the surface layer by the subsoiler. Conversely, repeated

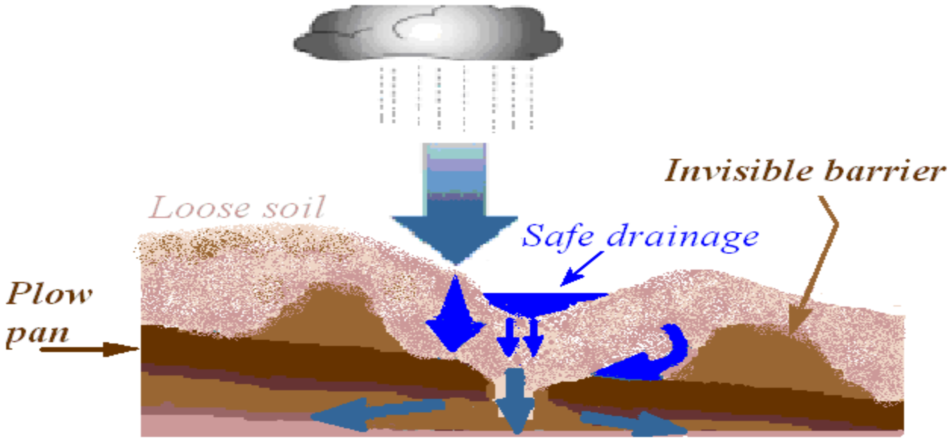

Figure 1. Schematic representation of improved tillage system whereby surface runoff is reduced by allowing more infiltration through the disrupted plow pans and by redirecting flow along the contour using invisible barriers (adapted from Temesgen et al., 2009).

cross plowing using traditional *Maresha* plow resulted in higher bulk density which ultimately resulted in poor soil-water conduction. Similar studies in the Ethiopia showed that tillage systems had no significant effect on soil physical properties after three years experiment with bulk density value of 1.35, 1.38, 1.39 gcm^3 for conventional tillage, strip tillage system with sub-soiling (STS) and strip tillage system (ST), respectively (Temesgen et al., 2007).

Soil bulk density, which is regarded as the sign of compactness and porosity in turn, depends on the types of tillage implements, soil organic carbon and tillage method and plowing depth (Lal, 1995). Burayu et al. (2006) reported the bulk densities of no tillage at 0-15 cm (1.16 gcm^3) and 15-30 cm (1.20 gcm^3) were significantly higher than that of conventional tillage for both soil depths (1.09 gcm^3) and (1.10 gcm^3), respectively. However, there was no indication of compaction as there was low bulk density for both tillage systems. This might be attributed to low effect of animal traction to compact soil. After harvesting, it was found that at both soil depths the moisture content of both tillage systems was the same. Permanent bed had higher macropore (0.070 m^3 m^{-3}) compared to traditional tillage (0.063 m^3 m^{-3}), while Terwah (0.055 m^3 m^{-3}) had the lowest value (Araya et al., 2010). The bulk density and void ratio at oven dryness were 1.87 Mg m^{-3} and 0.39%, respectively. Oicha et al. (2010) reported that tillage systems had no significant difference on bulk density with a value of 0.98 ±0.031, 1.05±0.004 and 0.98±0.031 Mg m^{-3} for permanent bed, Terwah and traditional tillage, respectively. Muche et al. (2013) evaluated the impact of conservation tillage on soil loss and runoff in the year 2009-2010 in the northwest Ethiopia. They founded the overall bulk density values of 1.07±0.005 and 1.03±0.043 gcm^3 at 0-20 cm soil depth for traditional and conservation tillage practices, respectively.

Osunbitan et al. (2005) observed greater bulk density in no-till system in the 5 to 10 cm soil depth whereas Biamah (1999) found no differences in bulk density between the different tillage systems. Abu-Hamdeh (2004) also studied the effect of tillage treatments (moldboard (MB) ploughing; chisel ploughing; and disk ploughing) for comparison of axle load on a clay loam soil. He reported that the dry bulk density from 0 to 20 cm was affected by the tillage treatments and from 20 to 40 cm by axle load. The MB treatment caused the maximum percentage increase of dry bulk density at all depths. These results reflect a more compact soil layer at 0-10 cm depth than at the 10-20 cm depth. Sharma et al. (2011) observed that intensive tillage condition increased the bulk density (4.7 %) of a sandy loam soil as compare to the reduced tillage in rainfed condition.

Soil penetration resistance (PR) was measured by a penetrologger (Eijkelkamp®) at 15 randomly selected sites in traditional and conservation tillage treated fields in Enerata, Ethiopia. A sharp rise in penetration resistance had been observed starting from 10 cm reaching its maximum at about 20 cm, which is a typical plow pan for shallow tillage (Temesgen et al., 2012). Plowing up and down the slope in TT resulted in straight horizontal soil layer differentiated by a sharp line, which led to accelerated flow in TT preferentially in the furrows that are laid along the slope. However, after applying CT narrow deep trenches were made along the contour that slow down the movement of water along the slope resulted in the fill and spill flow process. This reduces surface runoff and soil erosion and facilitates deep percolation of soil moisture (Figure 1).

Similar field trials in the central highlands of Ethiopia showed that, broad bed and furrows significantly increased PR ($p<0.05$) both under moist and dry soil conditions, may be because it involved a primary tillage when the soil was dry, followed by four tillage operations at about field capacity moisture content, when the soil approached an optimum moisture content for compaction (Erkosa, 2011). In contrast, reduced tillage (RT) has resulted in the lowest PR, despite its increased crusting. This is because PR was measured up to the depth of 15 cm while the effects of surface crust was limited to the upper few millimeters. Thus, reducing the frequency of tillage may reduce soil compaction, improve aeration and enhance root growth and access to nutrients and water.

Table 1. Mean soil moisture content at different soil layers in response to traditional and conservation tillage under wheat crop in Ethiopia (Temesgen et al., 2012; Kidane et al., 2012).

Depth (cm)	Location in the plot	Average soil moisture (% vol.) TT	CT	References
0-15	Upper side	31.27 (± 0.48)by	30.37 (± 0.67)ax	
	Lower side	34.61 (± 0.30)bx	33.11 (± 0.66)ay	Temesgen et al., 2012
15-30	Upper side	29.42 (± 0.90)ax	32.17 (± 0.32)bx	
	Lower side	31.59 (± 0.21)ay	33.51 (± 0.28)by	
0-10	Upper side	30.5 ±0.003[b]	27.5±0.003[a]	Kidane et al., 2012
	Lower side	32.3 ±0.003[c]	27.8±0.002[a]	

Mean values followed by dissimilar letters (a–b) across a row and letters (x–y) along a column with in a depth are significantly (α = 0.05) different.

Table 2. Runoff volume and runoff coefficient for the entire the cropping season after treated with conservation tillage practices (Gebreegziabher et al*.,* 2009; McHugh et al., 2007).

Treatment	Total runoff volume m^3 ha^{-1}	Average runoff Coefficient (%)	References
TT	653a	15.5a	
Terwah	381b	9.0b	Gebreegziabher et al*.,* 2009
PB	255c	6.0b	
Maresha	41a	0.18a	
Sub-soiling	36b	0.16a	McHugh et al., 2007
Tied ridge	25c	0.11c	

Mean values followed by dissimilar letters (a–c) along a column are significantly (α = 0.05) different.

Table 3. Suspended sediment concentration and total soil loss under different conservation tillage treated plots (Gebreegziabhier et al., 2009; McHugh et al., 2007; Temesgen et al., 2012).

Crop type	Treatment	Average suspended sediment concentration (g l^{-1})	Total soil loss in the cropping season (ton/ ha)	References
	TT	56.3a	19.5a	Gebregziabher et al.,2009
Tef	Terwah	33.94b	7.6b	
	PB	28.32c	4.7b	
Tef	CT	3.02 (± 0.59)a	10.73 (± 1.85)a	Temesgen et al., 2012
Wheat	TT	3.11 (± 0.54)a	11.76 (± 1.95)a	
Wheat	CT	3.21 (± 0.53)a	5.41 (± 0.87)b	
Tef	TT	3.46 (± 0.80)a	8.55 (± 1.31)a	
	Maresha	1.3	11.4	McHugh et al., 2007
Sorghum	Sub-soiling	1.7	18.9	
	Tied ridge	2.4	16.4	

Levels not connected by same letter are significantly different at level α= 0.05.

Soil Chemical Properties

The amount of organic matter in a soil is often used as an indicator of the potential sustainability of conservation tillage system (Astatke et al., 2003; Kidane et al., 2012; Lal, 2004; Nyssen et al., 2008; Tadesse et al*.,* 1996). Soil organic matter plays a key role in nutrient cycling and can help improve soil structure. The soil organic matter is the second biggest carbon pool of the planet after the oceans (Lal, 2004). It is essential to control erosion, water infiltration and conservation of nutrients and is related with the soil quality. Increases in the bulk density usually result in large decreases in water flow through the soil.

Soil organic carbon is significantly affected by tillage methods (Lal, 1997). A tillage research reported that, soil organic matter decreased as tillage intensity increased and the greatest decreases were observed in deep tillage (Alamouti and Navabzadh, 2007). The amount of soil organic matter (SOM) and total soil nitrogen (TSN) increased in both tillage systems (Astatke et al., 2003; Burau et al., 2006). The increment of soil organic matter content for no-tillage over conventional tillage were 0.30 and 0.28% at 0-15 cm and 15-30 cm soil depths, respectively. Total soil nitrogen was increased by 0.03% in no-tillage over conventional tillage. Similarly soil organic matter and total soil nitrogen remarkably increased in rotation plot as compared to continuous monoculture plot within the same tillage system. This might be that no tillage had the ability to increase soil nutrients equally for continuous and rotation crops.

Interestingly soil organic matter (SOM) was significantly higher in traditional tillage (2.49%) compared to conservation tillage (2.33%) and soil compaction and hard pan formation are mentioned as a contributing factors for this result (Nyssen et al., 2000). Moreover, Lal (2000) confirmed that, organic matter has a strong positive effect on infiltration of water into soils and the effect is mainly due to decrease in bulk density and improvements in aggregation and structure. Tillage systems had no significant effect on soil physical and chemical properties after the three years period of the experiment (Temesgen et al., 2007). The result revealed 0.62, 0.62 and 0.64 % of soil organic carbon for conventional tillage, strip tillage system with sub-soiling (STS) and strip tillage system (ST), respectively. They point out that high temperatures in the study area (average maximum 31°C and minimum 15°C) could cause high oxidation of organic carbon.

Tsigie et al. (2011) discussed a research conducted on crop residues as animal Feed Vs conservation agriculture in the central highlands of Ethiopia. Soil pH values, organic carbon (OC), nitrogen and phosphorus measured for samples taken after harvesting were significantly (p<0.01) affected due to the application of different soil fertility management treatments. The highest pH value (5.75) was recorded from 3 ton/ha of compost and half dose of the recommended rate of NP fertilizer. Permanent bed had significantly higher (p = 0.0003) soil organic matter (SOM) than traditional tillage and Terwah, while the latter two didn't show a significant difference (Oicha et al., 2010). Many authors studied the impact of conservation tillage on soil loss in the highlands of Ethiopia (e.g. Muche et al., 2013). The result indicated soil organic matter had no significant differences between traditional and conservation tillage with the value of 2.12±0.006 and 2.13±0.005, respectively. The crop residue retention has been reported to increase soil organic carbon and biotic activity (Gebreegziabher et al., 2006; Gebremichael et al., 2006) thereby decreasing bulk density, particularly near the soil surface in the ST and NT plots under investigation.

Selected soil water condition

Infiltration

Quantitatively, infiltration rate (IR) is the flux or volume of water entering the soil per unit area in unit time. Infiltration is governed by gravity and capillary action. Tillage disturbs the natural channels that have formed in a soil. It plays a vital role in the conservation of soil moisture at different depths in the rainfed cultivation. Tillage would also improve the soil condition by altering the mechanical impedance to root penetration, hydraulic conductivity and water holding capacity (Dexter and Birkas, 2004). Abu-Hamdeh (2004) observed that mould board plough caused a maximum decrease in the infiltration rate, while with Chiesl plough and CS treatment had the lowest effect.

Conservation tillage provides the best opportunity for halting degradation, restoring and improving soil productivity (Temesgen et al., 2008). It conserves water by reducing evaporation. It also creates a more favorable soil water regime by improving surface soil properties that favor more infiltration and conduction of water to lower soil profile and consequently more reserve of soil water. CT increase soil water infiltration substantially compared to the infiltration of the moldboard-ploughed soil (Rockstrom, 2000). Conservation tillage is effective in reducing the loss of many surface water contaminants including sediments, pesticides and nutrients. Infiltration rate was greater for deep tillage (1.405 cm h^{-1}) and lower for traditional tillage systems (1.234 cm h^{-1}) (Brhane et al., 2006). They concluded that, the increase in infiltration rate with deep tillage probably reflects the decrease in soil bulk density.

The infiltration rate in the winged subsoiler treated plots was twice higher than the traditionally tilled plots (Kidane et al., 2012). The initial and steady state (60 min) infiltration rates under winged subsoiler (WS) plots were 0.84±0.005 and 0.1±0 cm min^{-1}, respectively. On the other hand, 0.54±0.006 and 0.05±0.004 cm min at 01 and 60min were observed under the traditional tillage (TT) treated plots.

Similarly, cumulative infiltration under winged subsoiler was considerably higher compared to the TT with values of 16.92±0.17 and 11.6±0.11 cm, respectively. Infiltration rate and cumulative infiltration in the winged subsoiler treated plots exceeded that of the traditionally plowed plots. Compared with the traditional tillage, the winged subsoiler treated plots resulted in better moisture retention, high infiltration, high tillage depth and low soil evaporation. Unlike traditional tillage system, based on soil inversion which impedes water infiltration and root penetration, conservation tillage seeks to enhance soil infiltration and productivity at the expense of water logging and high surface runoff (Temesgen et al., 2012; Temesgen et al., 2008; Temesgen et al., 2007). Moreover, conservation tillage systems provide farmers with an effective tool to maximise rainfall infiltration into the soil, reduce runoff and build up water holding capacity of the soil.

Moreover, conventional tillage practices using traditional tools have been found to cause sub-surface plough hard (pans), which impedes root penetration and water infiltration and reduce soil moisture storage capacity (Astatke et al., 2003; McHugh et al., 2007). The traditional *Maresha* often plow between 8-10cm soils depths, depending on the conditions of the land and hence cannot penetrate the hardpans (Temesgen et al., 2007). As it can be seen in Figure 1, conservation tillage has a profound effect on rainfall partitioning through disrupting the hard pans and encourage infiltration and reduce surface runoff. Subsoil cultivation is a technique that cuts soil deeper than achieved with traditional tillage (McHugh et al., 2007). Hardpans and soil compaction caused by repeated tillage to the same depth for generations and animal trampling has been reported in Ethiopia (Mwendera and Mohamed, 1997), but little is known about their prevalence in croplands and the level of impact on agricultural yield. A study tested the effectiveness of sub-soiling implemented with an oxen-drawn subsoil cultivator recently developed by the Integrated Food Security Program (IFSP) in Debre Tabor, Ethiopia. The tested subsoiler cut the soil at 30–50 cm intervals an additional 6–12 cm below the 6–15 cm tillage depth of conventional tillage with *Maresha* (McHugh, 2006; Nyssen et al., 2000; Gebregziabher et al., 2006). Consequently, surface runoff and soil evaporation had been reduced through encouraging water holding capacity of the soil, infiltration and soil moisture availability.

The continuous removal of crop residues coupled with minimal use of farmyard manure results in the mining of nutrients, organic matter depletion and weakening of soil structure (Burau et al., 2006). These processes lead to increased runoff and erosion losses that are strongly linked to topsoil. Water infiltration is improved by increase ground cover which prevents crust formation on the soil surface and formation of macro pores by soil biota (e.g. earthworms) which increase in number under the protective soil cover breaking of hardpans (e.g. plough pans) with an animal or tractor drawn subsoiler or pitting in case of manual labour. These operations enhance infiltration into deeper soil layers (Steiner and Rockström, 2003). The infiltration rate of the surface layer increased significantly ($p = 0.05$) immediately after conversion from acacia-based grassland to cultivated land. Thereafter, there was a weak decreasing trend ($p > 0.05$, $R^2 = 0.24$) in infiltration rate with years of cultivation (Biazen et al., 2011).

Soil Moisture Conservation

Green water management in rainfed agriculture does not get enough attention at the policy or development program level (Rockstrom, et al., 2009). In general, this area of water management is ‘a blind spot’. However, blue water resource development (dams, hydropower, and irrigation) typically receives all the political attention and financial resources. The importance of green water management, the factors that drive it and the practical improvements that can be made are not well understood (Rockstrom, 2003).

No-tillage systems are very effective in reducing evaporation from soil, to increase the water holding capacity and soil moisture and increase water infiltration (Benjamin, 1993; Burayu et al., 2006). The system increase green water through the use of soil covers reduces water evaporation and therefore water is available for crop production. The covered surface of no-tillage fields acts as a protective skin for the soil. This soil skin reduces the impact of raindrops and buffers the soil from temperature extremes as well as reducing water evaporation (Descheemaeker et al., 2006; Lal, 2000). Similarly tied and open ridge increased seasonal root zone soil moisture 15–24% McHugh et al. (2007). Sub-soiling slightly (3%) increased and no till slightly decreased soil moisture but were not statistically different from conventional tillage.

Temesgen et al. (2012) conducted an experiment on the impact of conservation tillage on hydrological and agronomy on famer’s fields from 2009-2010 years. The soil moisture measurements had been taken continuously at the lower and upper sides of each plot, for a period of one month only (due to vandalism). Although the measurement period is short, the sampled results clearly revealed that soil moisture in TT (average 34.6 % vol.) is significantly higher ($\alpha = 0.05$) than that of CT (average 31 % vol.) at 0– 15 cm depth while the reverse holds true at 15–30 cm layer (33.5 and 31.6 % vol.), in CT and TT, respectively (Table 1).

Similar studies had been conducted in an on-farm experiment in the northwestern highlands of Ethiopia (Kidane et al., 2012). There were significant differences (P< 0.0001) in soil moisture content between tillage treatments as well as in the upper and lower sides of the plots. Significantly (P ≤ 0.05) different soil moisture contents between the upper and lower sides of the *fanya juus* were observed under traditional tillage practice (0.305±0.003 and 0.323±0.003 m^3 m^3, respectively) see Table 1. On the other hand, the mean moisture content in plots treated with winged sub-soiler was 0.275 ±0.003 and 0.278±0.002 m^3 m^{-3} for the upper and lower sides of the plot, respectively. Thus, soil moisture content was consistently higher at the lower side as compared to the upper side of the bund in the traditionally plowed plots. The authors argued that the disruption of plow pan through deep contour plowing using winged subsoiler could be the reason for enhanced infiltration and more uniform distribution of soil moisture leading to less water logging. Sharma et al. (2011) observed increase in soil moisture content (12.4%, 16.6%) in minimum tillage (MT) in maize and wheat rotation, respectively in rainfed farming as compared to conventional tillage. This could be attributed to greater residues and organic matter in the soil surface than the subsurface proportions of the soil. According to Biazen et al. (2011) the cumulative evaporation observed over 5 consecutive days following the last rainfall event increased by 2.4 times in the 35 years old cultivated land from the acacia-based grassland. There was also a strong correlation ($R^2 = 0.86$) between α (the slope of the cumulative evaporation versus the square root of time) and an increase in the years of cultivation. They had concluded that long-term *Maresha* cultivation along with the present soil management makes the maize crop susceptible to drought and dry-spells.

Surface Runoff

Runoff is an important water balance component in rainfed agriculture. Studies shows that runoff from a particular storm is mainly a function of the soil infiltration rate, surface storage and storm intensity (Descheemaeker et al., 2006). Water losses through surface runoff can be reduced by ground cover (crop residues and cover crops) which slows down the water flow and prevents surface crusting as well as by implementing ripping, “open plough furrow” (planting furrows), planting pits, tied ridges which collect and store access water (Steiner and Rockström, 2003). Similarly, in a recent study carried out in northern Ethiopia on steep slopes (> 20%) Descheemaeker et al. (2006) found that runoff become negligible when vegetation cover exceeds 65% of the surface.

On an experiment carried out on sandy loam soils with a surface slope of 1%, Babacar et al. (2005) found a runoff coefficient (ratio of total Runoff to Precipitation during the experiment) ranging between 8 and 24% on plots ploughed perpendicular to the slope while the equivalent value for plots ploughed parallel to the slope was between 18 and 61%. Permanent raised beds with contour furrows at 60–70cm interval significantly (P < 0.05) reduced runoff volume, runoff coefficient and soil loss as compared to traditional tillage (Gebreegziabhier et al., 2009). As it can be seen in Table 2, a total of 255, 381 and 653 m^3 ha^{-1} runoff was recorded from permanent bed, terwah and traditional tillage, respectively during the whole cropping season. They have founded over 60% decrease in total runoff using wheat as a test crop in the previous growing period, while Oicha et al. (2010) founded 50% decrease in permanent bed compared to traditional tillage. Araya et al. (2014) conducted field trials on a rainfed field in Tigray, northern Ethiopia. The authors reported significantly different (p<0.05) runoff coefficients averaged over 8 years were 14, 20 and 27% for Derdero (DER), Terwah (TER), and traditional tillage (TT), respectively. Mean soil losses were 4 ton/ ha y^{-1} in DER, 13 in TER and 18 in traditional tillage, respectively.

McHugh et al. (2007) studied the effect of conservation tillage on runoff. At the steepest slope gradient of 9–11% they had observed significantly (P<0.05) more runoff across tillage treatments with over 20% of the total seasonal rainfall lost to surface runoff compared with the 0–3% and 4–8% slope gradient generating less than 15% rainfall runoff (Table 2). Among tillage treatments, conventional tillage with *Maresha* produced the most surface runoff volume followed by sub-soiling, no till with stalk mulch and tied ridge in that order. Sub-soiling produced less (12% less *belg* 2004 and 8% less *kremt* 2004), but statistically similar runoff depth compared to conventional tillage with *maresha.* They have noted that the effect of sub-soiling on runoff was more significant on the 0–3% slope gradient during both seasons.

Temesgen et al. (2012) evaluated the hydrological and grain yield impact of conservation tillage on field experiment and they identified that more surface runoff occurred for traditional tillage compared to conservation tillage, and that the differences between the two was more in the wheat plot than in *tef*. The average reduction of surface runoff was 48 % in the wheat plot due to the application of CT, with the daily averages of 4.8 and 2.5 mm d^{-1} in TT and CT, respectively. In *tef* the surface runoff reduction was 15 % with an average of 4.5 and 3.8 mm d^{-1} in TT and CT, respectively. Similarly significantly different (p<0.05) mean soil losses of 4.4, 12.5 and 18 ton/ha y^{-1} were recorded for DER, TER and conventional tillage, respectively (Araya et al., 2012). The mean runoff was 458, 706 and 925 m^3/ha y^{-1} from DER, TER and conventional tillage treated plots, respectively. They concluded that the improved local tillage practices of DER and TER planting system can be an alternative to the conventional tillage system to reduce runoff and soil loss and improve soil moisture and crop yield on Vertisol.

Temesgen et al. (2007) observed in field trial on conservation tillage compared with traditional tillage in a moisture deficit area in Ethiopia. Sub-soiling along the same lines (STS) resulted in the least surface runoff (Qs =17 mm-season^{-1}), the highest transpiration (T =196 mm-season^{-1}) and the highest water productivity using total evaporation (W_{PET}=0.67 kg-m^{-3}) while TT resulted in highest surface runoff (Qs=40 mm-season^{-1}), least transpiration (T =158 mm-season^{-1}) and low water productivity (W_{PET}=0.58 kg-m^{-3}), respectively. Araya et al. (2011) reported runoff values of 46.3, 76.3 and 98.1 mm from DER, TER and conventional tillage, respectively. Soil management can have different impacts on runoff under different crops (Gebreegziabher et al., 2009).

Rainfall generated significant surface runoff with as much as 66 % of storm depth leaving plots as overland flow (McHugh, 2006). Cropland which had the lowest infiltration rates produced over twice as much runoff as rangeland with a mean runoff coefficient of 27 % (runoff depth as percentage of rainfall depth).

Soil Loss/Sediment Yield

Soil erosion is a serious problem in the Ethiopian highlands that increased sedimentation of reservoirs and lakes. Sediment export rates in the Ethiopian highlands are characterized by important changes in sediment supply (Descheemaeker et al., 2006; Nyssen et al., 2011; Nyssen et al., 2009; Nyssen et al., 2005; Nyssen et al., 2000). Soil management and tillage practices related sediment production at plot scale and quantify the magnitude of sediment delivery is essential. Oicha et al. (2010) studied conservation agriculture (CA) experiment on a farmer’s field from 2005 to 2006 at Adigudom, Ethiopia. The treatment plots were uniform in soil type and all external inputs except tillage practices. Significant difference had been observed, the difference in the sediment concentration of the runoff events was induced by the treatments. The highest sediment concentration in the traditional ploughing could be due to the frequent tillage, which disaggregated and eased detachment of the soil. They noted that the absence of depression storage in the traditional cultivation could also ease the transportation of sediment. The relatively higher sediment concentration in the terwah system as compared to the permanent raised beds could also be attributed to the higher frequency of tillage in the terwah system, which disperses the soil aggregates and eases transportation by flowing runoff. The total soil loss increased during the crop-growing periods. Many studies have indicated that reduced tillage in conjunction with crop stubble retention decreases soil erosion and rainfall runoff and maintains soil structure and long-term productivity (e.g. Erkossa, 2011; Gebreegziabhier et al., 2009; Muche et al., 2013; Temesgen et al., 2012; Temesgen et al., 2009; Temesgen et al., 2007).

In an experiment conducted in 2005 and 2006 cropping seasons in northern Ethiopia, significant difference ($p<0.05$) in soil loss in wheat and *tef* cropped field was observed (Araya et al., 2010). The soil loss reduction in 2005 for wheat was 76% in permanent bed (PB) while 61% in Terwah (TERW) as compared to traditional tillage (TT). Similarly, the reduction in soil loss was 86% in PB and 53% in TERW as compared to TT in 2006 for *tef.* In order to evaluate the effect of conservation agriculture on runoff, soil loss and crop yield, an experiment was carried out in a rainfed field using a permanent raised bed planting system for 3 yrs (2005–2007) in Adigudem, northern Ethiopia (Araya et al., 2011). Results from monitoring over 3 years showed that soil loss and runoff were significantly higher ($P< 0.05$) in traditional tillage followed by TER and Derdero (DER). Similarly the average soil losses of 5.2, 20.1 and 24.2 ton⁄ha were recorded from DER+, TER and TT, respectively.

Although the concentrations of sediment decreased, the increase in total runoff compensated for the increased total soil loss result (Oicha et al., 2010). In the traditional ploughing, the soil loss was highest throughout the rainy season as compared to the terwah system and permanent raised bed planting. A soil loss of 3.07 ton/ ha was recorded in the TT for a rainfall event of 35 mm on 25 July (Araya et al., 2011). The corresponding soil losses from the terwah system and PB were 0.85 and 0.60 ton/ ha, respectively. The lesser soil loss in the permanent raised beds as compared to the other two treatments is due to the capacity of the furrows made at close interval (60–70 cm) to harvest excess water during intensive rains, which would otherwise remove more soil from the beds. Besides, the less or no tillage in the permanent bed planting system could also contribute to less soil detachment by rainfall splash and hence less soil exported from the treatment plots.

McHugh et al. (2007) evaluated the performance of conservation tillage techniques on clay loam soil during three cropping seasons (2003-2004) in an on-farm experiment in the drought-prone North Wello zone of the Ethiopian highlands. The tested tillage techniques were sub-soiling, open and tied ridges, no till and conventional tillage with the local *Maresha* plow (Table 3). They founded that tied ridge and no till significantly reduced seasonal soil loss by up to 11 Mg ha^{-1} during seasons with moderate intensity storms, but during a season with high intensity storms tied ridge on over 9% slope gradient increased soil loss up to 35 Mg ha^{-1}. The increased soil disturbance of sub-soiling led to higher soil loss rates (up to 32 Mg ha^{-1}) than conventional tillage during all seasons. They argued that, slope gradient and tillage techniques affected both suspended sediment and total sediment losses suggesting impacts on erosion and transport of both fine and heavier soil particles.

Sediment yield on below 3 % slope for all plots was low at less than 2 Mg ha^{-1}. However, on the 9-11 % plots soil loss rates for all tillage methods exceeded twice the sustainable threshold of 6 Mg ha^{-1} (McHugh, 2006). These results suggest that soil conservation planning needs to focus on appropriate watershed management practices that can effectively control cropland erosion on slopes greater than 8 %.

Gebregziabher et al. (2009) founded the total soil loss was significantly reduced with the permanent raised beds (4.7 ton/ha) and the terwah system (7.6 ton/ha) as compared to the traditional ploughing (19.5 ton/ha) (Table 3).

There was higher soil loss from terwah ploughing than from permanent bed. A total suspended sediment concentration of 56.3gl^{-1}, 33.94 and 28.32 gl^{-1} were recorded in the traditional ploughing, terwah and permanent bed, respectively. The authors argued that this was attributed to the relatively shallow depth and wider furrow spacing, which were filled with sediment from the flat beds after the frequent and intensive rain in mid August. The repeated tillage in terwah cultivation could also increase the soil loss as compared to the permanent raised beds. The authors concluded that the use of permanent raised beds if combined with crop mulching and crop diversification is an important component for the development of sustainable conservation agricultural practices in the region.

Temesgen et al. (2012) demonstrated reduced sediment yield in both wheat and *tef* fields due to the application of conservation tillage (CT) (Table 3). Reduced surface runoff in CT led to reduce soil erosion thereby significantly reduced water-logging was observed behind soil conservation structures (SCS) in CT compared to traditional tillage. Nyssen et al. (2011) studied the effect of conservation tillage (permanent bed system) in northern Ethiopia. The result revealed decreased runoff (51%) and soil loss (81%) which allows protection of the down slope areas from flooding. A slow process of soil nutrient build-up and soil structure improvement had been observed.

Grain yield

In an on-farm experiment, McHugh et al. (2007) founded that ridges significantly increased soil moisture and grain

Table 4. Biomass and grain yield of wheat and *tef* from conservation and traditional tillage at Enerata, Ethiopia (Temesgen et al., 2012; Oicha et al., 2010; Araya et al., 2012; Temesgen et al., 2007; Erkosa et al., 2006).

Crop type	Treatment	Grain yield (kg/ ha)	Total biomass (kg/ ha)	References
	CT	2396 (± 440)b	3960 (± 340)a	
Wheat	TT	1985 (± 245)b	4167 (± 797)a	Temesgen et al., 2012
	CT	2685 (± 462)b	5833 (± 872)a	
Tef	TT	3470 (± 429)a	1868 (± 367)b	
	TT	1173 (50)a	6.7 (0.18)a	Oicha et al., 2010
Tef	Terwah	925 (99)b	4.5 (0.64)b	
	PB	678 (73)c	3.0 (0.69)b	
	DER	2.03±0.21a	nd	Araya et al., 2012
Wheat	TER	1.97±0.15a	nd	
	TT	1.53±0.06a	nd	
	Open STS	993 (c)	3576 (c)	
Maize	Open ST	1250 (bc)	4347 (bc)	Temesgen et al., 2007
	Closed STS	1332 (ab)	4875 (ab)	
	Closed ST	1587 (a)	5750 (a)	
	BBF	1296	nd	
Tef	Green manure	1284	nd	Erkosa et al., 2006
	Ridge and furrow	1274	nd	
	Reduced Tillage	1379	Nd	

Standard error of the mean in parenthesis, Values followed by dissimilar letters along a column are significantly different (α = 0.05), nd = stands for no data.

yield and reduced soil loss, whereas no-till minimized soil loss, but reduced yield. Similar field trial on conservation tillage in northwestern Ethiopia showed that grain yields of wheat and *tef* increased by 35 and 10 %, under CT and TT treated plots, respectively (Temesgen et al., 2012). There were significant differences between compacted and non-compacted plots in both biomass (P=0.0007) and grain yields (P=0.0035). Greater biomass (4211kg/ha) and grain (1222kg/ha) yields were obtained from conservation tillage treated plots. They agreed that this was due to high variation in soil fertility as replications were made in different farmers' fields (Table 4). Participating farmers noticed the differences in biomass and grain yield with their own possible reasons in that (1) reduced soil erosion, (2) better weed control, (3) extended period of soil wetness and (4) reduced water logging in CT.

During a season with moderate intensity rainfall, open and tied ridge increased sorghum yield by 67–73% over the control (730 kg/ha) while no till decreased yield by 25% (McHugh et al., 2007). Sub-soiling significantly increased grain yield by 42% during *kremt* 2003 and 33% during *kremt* 2004 compared to conventional tillage with *maresha*. According to Araya et al. (2011) the yield of wheat in 2007 was significantly higher in Derdero followed by Terwah. They had noted that the terwah system is recommended as a first measure for wider adoption to reduce runoff and soil loss and to increase crop yield.

Broad bed and furrow (BBF) tillage significantly increased the grain yield of lentils by 59% (from 1029 to 1632 kg/ha) as compared to the control (Erkosa et al., 2006). On the other hand, reduced tillage resulted in the highest grain yield of wheat (1862 kg/ha) and *tef* (1378 kg/ha) as compared to 1698 kg/ha of wheat and 1274 kg/ha of *tef* for the control although the increase was not statistically significant. They concluded that BBF is the most profitable option for lentil with 65% increase in total gross margin.

Reduced tillage and maintenance of ground cover with crop residues may increase water availability to the crop and increase grain in semi-arid areas of Ethiopia. According to Mesfine et al. (2005) the application of 3 ton/ha of *tef* straw increased grain yield of sorghum by 70% in conventional tillage and by 46% in zero tillage treatments in the central rift valley of Ethiopia. Mulching has to do with reducing unproductive water loss. Mean soil water throughout the season was 16% more with 3 ton/ha application of straw compared to without straw application. They concluded that ground cover with crop residues is necessary to achieve acceptable yield with zero tillage in low moisture stress areas of Ethiopia.

A study conducted in the semi-arid areas of northern Ethiopia demonstrated sorghum yield increment by 7 to 48% due to the effect of conservation tillage integrated with fertilizers compared to the traditional tillage (Brhane, 2012). The increment of yield and yield components due to the tied-ridging and fertilizer interaction effects were higher for *Chibalas* compared to *Woitozira*. The mean sorghum crop yield for *Chibal* was 1.45 ton/ha and that of *Woitozira* was 1.31 ton/ha. The author concluded that suitable time of tied-ridging integrated with proper rate of fertilizer should be adopted for effective increase of crop production in the semi-arid areas of northern Ethiopia.

Integrated soil and crop management practices should be addressed simultaneously in order to reduce runoff and soil erosion associated nutrient losses, increase water infiltration and nutrient availability for crop production (Breman, 2001). Plot level experiment was conducted in 2002 and 2003 cropping seasons in Abergelle northern Ethiopia (Brhane, 2006). The investigation indicated tied-ridging increased sorghum grain yield and soil water by more than 40 and 25%, respectively, as compared to the traditional tillage practice (shilshalo).

Araya et al. (2012) compared conservation tillage practices in the Adigudom area of Tigray region. The average barley yield was 1650 kg/ha above the bund, which was 43 % higher than below the bund. The average grain yield of wheat over three years was 2.46, 2.02 and 1.61 ton/ha for DER, TER and TT, respectively (Table 4).

Moreover, field test results in the semi-arid Ethiopia revealed that almost doubled grain yield was obtained from ridging, sub-soiling and wing plough (average of *tef* grain yield of 1076, 1044 and 1040 kg/ ha respectively) compared to conventional tillage which resulted in the lowest yield with an average of 540 kg/ha (Rockstrom et al*.*, 2009).

The major reasons for the increase in yields were better moisture availability, improved soil fertility and better root growth as a result of conservation tillage application (Belay, 1998; Lal, 1997; Lal, 2000; Temesgen et al., 2008). They concluded that comparing to shallow tillage, deep tillage increased wheat yield by 15%. Deep ripping and sub-soiling techniques results in 60 % yield increments, as they increased water infiltration and reduce surface runoff (Temesgen et al., 2009). Furthermore, Temesgen et al. (2007) reported the improved *Maresha* plow in Ethiopia reduces the time required for plowing and increase the yield of *tef* by 20% (Table 4) compared to the control. They noted that through the use of conservation tillage the problems of low water productivity and low yields could be addressed via improving the soil-water conditions of the agricultural fields. On field experiment four methods of land preparation (broad bed and furrow, green manure, ridge and furrow and reduced tillage) were tested in the central highlands of Ethiopia (Erkosa et al., 2006). They discovered that broad bed and furrow significantly increased the grain yield of lentils by 59% (from 1029 to 1632 kg/ha) as compared to the control (Table 4). On the other hand, reduced tillage resulted in the highest grain yield of wheat (1862 kg/ha) and *tef* (1378 kg/ha) as compared to 1698 kg/ha of wheat and 1274 kg/ha of *tef* for the control although the increase was not statistically significant.

Results of grain yield analysis indicated a significant difference between PB (with a mean of 678 kg/ ha) and TERW (mean yield of 925 kg/ ha) (Oicha et al*.*, 2010). There was also a significant difference (p= 0.0016) among treatments in weed infestation. The mean mass of weed dry matter during the first weeding in the TT, TERW and PB was 77, 125 and 242 kg/ha, respectively (Table 4). They have concluded that the application of conservation tillage brought significant effect of agricultural productivity compared to the control.

Constraint to the Adoption of Conservation Tillage in Ethiopia

The adoption of conservation tillage (CT) is constrained by a number of factors that are both environmental and socio-economic (Castrignano et al., 2001). While all facts prove the superiority of CT compared to conventional tillage adoption by smallholder farmers are still low. A number of reasons, mainly economic and social ones, prevent farmers to change their farming systems (Steiner and Rockstrom, 2003). The semi-arid region of Ethiopia is characterized by low and erratic rainfall coupled with high evaporation rates, which makes it difficult to produce sufficient biomass for soil cover (Tenalem, 2007). Moreover, lack of grazing during dry seasons and the system of communal grazing restricts the possibility of leaving crop residue on the field after harvest (Kossilla, 1988). Zero tillage without mulch can produces significant losses. The semi-arid region of Ethiopia is characterized by low organic matter content (Mulatu and Regassa, 1986) which makes them prone to compaction.

The direct application of conservation farming (CF) has been constrained by several technical and socio-economic factors such as the need for dry season animal feed and high costs of herbicide are among others (Temesgen, 2007). The possible challenges for the future adoption of CF in Ethiopia include how to improve farmer awareness of CF benefits and how to efficiently incorporate green manure and cover crops.

The other major challenge for the adoption of conservation tillage is weed infestations associated with reduced tillage (Temesgen et al., 2007). Even though one of the primary purposes of tillage is weed control, with reduced tillage or zero tillage weeds become the serious challenge. Consequently, stallholder farmers are adversely affected by such invasive weeds and unless manual labour is applied herbicides are too costly for the poor peasants. Moreover, the high costs of conservation tillage implements have also affected the wider adoption of the technology (Steiner, 1998). It will be better if cost effective tillage technologies that take into account all smallholder farmers in the light of costly living conditions will make easy to adopt and increase yields from a drop of water.

Water-related problems under rainfed agriculture in the water scarce tropics are often related to high-intensity rainfall with large spatial and temporal variability, rather than to low cumulative volume of rainfall (Rockstrom, et al., 1999). Coefficient of variation ranges from 20 to 40 percent. The overall result of unpredictable spatial and temporal rainfall patterns indicates that a very high risk meteorological droughts and intra seasonal dry spells are the salient features of semi-arid Ethiopia (Atlabachew, 2006).

Obviously, mitigation of intra seasonal dry spell is a key to improve water productivity in rainfed agriculture in the semi-arid environments (Rockstrom et al., 2003b). According to the same authors there are three major avenues to achieve this: 1), maximize plant water availability (maximize infiltration of rainfall, minimize unproductive water losses (evaporation); 2), increase soil water holding capacity and maximize root depth; 3) Maximize water-uptake capacity of plants (timelines of operation, crop management and soil fertility management). Hence, maximum crop production will be achieved from scare rainfall through applying the means explained above. 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 (Nyssen et al., 2011).

CONCLUSION AND RECOMMENDATION

Conservation tillage is an important strategy for the adoption of soil and water conservation and to reduce runoff and soil loss by water erosion. For the last decades there have been several attempts to develop and implement often major modifications to the *marasha*, the traditional ox-drawn ardplough. Several findings on the effect of conservation tillage had indicated that, the implement improved soil properties, soil water conditions, reduced soil loss and runoff which in turn increased agricultural productivity under moisture deficit and high rainfall areas. Even though tillage changes soil properties, improved grain yields and reduced soil loss, the effects are usually inconsistent and not repeatable from place to place and year to year. This would be due to the complexity of changes in soil properties caused by tillage. Environmental and socio-economic factors especially weed infestations and unaffordable costs of the conservation tillage technologies are among the major challenges for its adoption in Ethiopia. Winged subsoiler, permanent raised bed, strip tillage with subsoiler, no tillage, tied ridge, broad bed and furrow integrated with crop residue are among the implemented and most promising conservation farming tools and techniques in Ethiopia. Hence, investment in these conservation farming systems is expected to lower land degradation and increase agricultural production. Based on the reviewed papers, the author suggested the following recommendations: (i) In the high rainfall areas, adoption of the technology has been hindered because of accelerated soil erosion, water logging behind bunds and incompatibility with the tradition of cross plowing, thus winged subsoiler is highly recommended. (ii) In moisture stressed areas high evaporation, low infiltration, reduced soil fertility, decreased ground water level and low water productivity are the major problems, hence, permanent raised bed, strip tillage with subsoiler, no tillage, tied ridge, broad bed and furrow integrated with crop residue are more appropriate. (iii) Locally adaptable improved and appropriate conservation tillage would be needed to maximize rainwater use efficiency, reduced soil loss and achieve a more sustained agricultural production in Ethiopia.

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