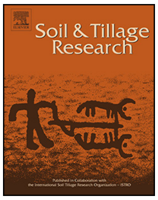
Soil & Tillage Research 148 (2015) 20–30

Contents lists available at ScienceDirect

Soil & Tillage Research

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



Agronomic and economic response of tillage and water conservation management in maize, central rift valley in Ethiopia

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ARTICLE INFO

Article history:
Received 11 August 2014
Received in revised form 29 October 2014
Accepted 2 December 2014

Keywords:
Conventional tillage
Conservation agriculture
Profitability
Rainfall Variability
Semiarid Ethiopia

ABSTRACT

In response to the intensive tillage in maize, operating under high seasonal rainfall variability, this study examined the agronomic and economic responses of tillage and water conservation management in the central rift valley (CRV) of Ethiopia. An experiment was laid out as a split plot design with conventional tillage (CT), minimum tillage (MT) and zero tillage (ZT) as main plots and mulch, no mulch and planting basin as subplots. The MT and ZT were considered as conservation agriculture (CA) plots. Results showed that CT had 13–20% higher grain yield than MT and 40–55% higher than ZT; and MT had 27–37% higher yields than ZT. Mulching had 23–33% and 14–19% higher grain yield than no mulch and planting basin respectively. The CT had 28 and 89% higher labor productivity and 6 and 60% higher gross margin than MT and ZT respectively. The MT had 37% higher gross margin than ZT. The highest yield response in CT resulted in its highest gross margin and labor productivity. This shows that regardless of water conservation management, CT yielded better agronomic and economic responses over CA. However, the practice of CT is highly constrained by the availability of draft power and the short window period for planting. Likewise, regardless of tillage management, mulching tended to be more attractive and promising in suppressing weed density and hence reducing labor demand for weeding, despite improving volumetric soil moisture content and maize yield. Yet the viability of practicing mulching is highly constrained by the widely practiced open grazing on stubble after harvest. Therefore, future studies are needed to further identify appropriate tillage and water conservation management which make maize more resilient to the high rainfall variability, and sustainably improve food security, and farmers' livelihoods in the CRV of Ethiopia.

1. Introduction

Crop production in Ethiopia is characterized by intensive tillage (Goe, 1987; Temesgen et al., 2008), low productivity due to soil degradation (Oicha et al., 2010) and inefficient use of water resources (Kassa, 2008). The high dependence of Ethiopian agricultural on rainfall makes smallholders' livelihoods highly vulnerable to climate variability (Deressa and Hassan, 2009). The soil in Ethiopia is ploughed by a traditional plough (locally called Maresha), which is pulled by a pair of oxen (Araya et al., 2012; Goe, 1987). Farmers plow their land from two to six times per planting depending on the crop that is to be planted (Aune et al., 2001). Among the major reasons for practicing intensive tillage are to prepare the seed bed, conserve soil moisture, reduce weed infestation, warm soil and increase productivity (Temesgen et al., 2008). However, repeated tillage has been reported to be the main cause of land degradation in Ethiopia (Araya et al., 2012; Nyssen et al., 2011; Temesgen et al., 2008). Complete removal of crop residues at harvest for domestic fuel and livestock fodder, and open grazing after harvest are additional factors causing land degradation (Girma, 2001). On other end, oxen rental cost for tillage is high and unaffordable to most farmers in Ethiopia (Aune et al., 2001) despite the low access to oxen particularly during peak time of planting. In the central rift vally (CRV) of Ethiopia, the repeated tillage at the shallow depths (13–16 cm) is often found to form plough pans below the plough layer (Biazin et al., 2011; Biazin and Sterk, 2013), which needs continuous manipulation (Temesgen et al., 2008; Biazin and Sterk, 2013) in order to increase infiltration and crop establishment. On other hand, intensive tillage increases evaporation of moisture from the soil surface, increasing vulnerability of crop to drought (Biazin and Sterk, 2013) particularly during dry and low rainfall season. Daily soil moisture evaporation was found to increase with the duration of cultivation with the Maresha showing that long-term Maresha cultivation, for

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http://dx.doi.org/10.1016/j.still.2014.12.001
0167-1987/© 2014 Published by Elsevier B.V.

instance, makes maize crop more vulnerable to drought and dry-spells in the CRV. As a result, an improved soil management and development of appropriate tillage which maximizes the rainwater use efficiency for achieving more sustainable crop production in the drought prone CRV of Ethiopia has been suggested (Biazin et al., 2011).

The CRV where this study was undertaken was previously a pastoral area covered by dense woodlands and without permanently cultivated land before the 1950s (Biazin et al., 2012; Garedew et al., 2009). In recent decades, however, it has been converted to cereal-based mixed farming system with maize as the major staple crop (Biazin and Sterk, 2013; Kassie et al., 2013). The rainfall exhibits high intra-seasonal variability with a coefficient of variation of 15–40%, and temperature increased significantly (0.12–0.54 °C per decade) over the past 30 years (Kassie et al., 2014), which imply severe challenges to the rain-fed crop production (Kassie et al., 2014; Biazin and Sterk, 2013). In response to the variable climatic conditions, this study tested early maturing, drought tolerant and nitrogen-use efficient variety of maize (*Zea mays* var. Melkassa-II) as an alternative to the mid and late maturing maize varieties used by the local farmers. Recently, due to change in the cropping calendar and variability in rainfall, the mid and late maturing maize varieties become highly vulnerable to early termination of rain in September in the cropping season (Biazin and Sterk, 2013). In the CRV, adopting the cropping calendar to the prevailing weather, and using drought-tolerant crop varieties were suggested to be among the main strategies for future adaptation to the current climate variability (Kassie et al., 2014). In experiments conducted in the Sudan Savannas in Northeast Nigeria, it was found that early-maturing cultivars of maize can escape droughts and provide yield even during years with below-average precipitation (Kamara et al., 2009). Apart from that, like in several other dry land areas in Ethiopia (Gebreegziabher et al., 2009), in response to rainfall variability, farmers in the CRV have recently started to practice *in-situ* water harvesting techniques locally called Shilshalo (Biazin and Sterk, 2013; Birhane et al., 2006). The Shilshalo is also practiced for breaking crusts or plow pans to improve infiltration (Biazin and Stroosnijder, 2012). This shows that there is a need for introducing additional *in-situ* soil moisture conservation management (mulching and planting basin in the current study) in order to complement with farmers' traditional practice of harvesting available rain water and to make maize more resilient to rainfall variability.

In this current study, conservation agriculture (CA) was evaluated for its agronomic and economic potential and for its feasibility in comparison with CT. This is because, CA has been proposed as an alternative to CT particularly in marginal agro-ecologies. Conservation agriculture is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment (FAO, 2012). It has three key elements including minimal soil disturbance (minimum tillage (MT) or zero tillage (ZT)); soil surface cover through the management of crops, pastures and crop residues (mulching); and crop rotations (FAO, 2013). The mulch gives the soil physical protection from the sun, rain and wind as well as feeding the soil biota (FAO, 2012). To reduce disease and pest problems, crop rotation is also important (FAO, 2012). Compared to CT, CA is a resource-conserving practice with the potential to increase plant available soil moisture, promote infiltration and reduce the costs of tillage operations (Hobbs et al., 2008; Thomas et al., 2007). Among the most important disadvantages of CA is the increased dependence on herbicides (Armstrong et al., 2003) and that the benefits of CA are realized gradually over long-term (Erenstein, 2003; Giller et al., 2009). Planting basin was also part of this study because conservation tillage with basin has been widely promoted in Southern Africa to be used by resource-poor farmers (Nyamangara et al., 2013) with limited access to draft power. Nyssen et al. (2011) also found permanent basins reducing oxen requirement under conservation tillage in Northern Ethiopia.

The practice of the CA concept has spread widely to many parts of the world and its area coverage has grown from 45 million hectares in 1999 to around 111 million hectares in 2009 (Derpsch et al., 2010). Conservation agriculture has been adopted in many different bio-physical environments elsewhere, however, its expansion in Africa has been limited; the area under CA on the whole African continent constitutes only 0.3% of the area worldwide (Derpsch et al., 2010). There is an ongoing debate regarding whether or not CA provides benefits for smallholder systems in Africa (Giller et al., 2009). The debate focuses mainly on how to promote CA in Africa under the existing soil, climate and socio-economic conditions (Knowler and Bradshaw, 2007; Vanlauwe and Giller, 2006). A major criticism is that the socio-economic conditions of smallholder farms are often insufficiently addressed in existing CA research. Critical constraints in its adoption appear to be the competing use of crop residues; increased labor demand for weeding; and the lack of access to, and high cost of external inputs (Giller et al., 2009). Although, FAO (2010) has proposed CA as a suitable alternative tillage practice to address the challenges of the predominantly rain-fed crop production systems of smallholder in Eastern Africa, only limited research on maize production with CA has been undertaken in Ethiopia. The CA practices were introduced to Ethiopia in 1998 by Sasakawa Global 2000 (SG 2000) on maize production (Matsumoto et al., 2004). The major findings from the limited research with regard to CA in Ethiopia are improved grain and biomass yields in *Teff*, maize and wheat (Araya et al., 2012; Kassie et al., 2009; Matsumoto et al., 2004; Nyssen et al., 2011; Rockström et al., 2009; Tadesse et al., 1996), improved water productivity (Temesgen et al., 2008), and improved soil organic matter (Nyssen et al., 2011) when practiced over medium to long-term. The central constraints in the adoption of CA packages in Ethiopia were found to be lack of farmers' awareness of CA benefits, difficulties in the incorporation cover crops, and the management of weeds (Kassie et al., 2009; Nyssen et al., 2011). The fact that socioeconomic, agronomic and environmental benefits of CA are realized gradually over long-term (Erenstein, 2003; Giller et al., 2009) may be additional challenges. Due to high risk-averse conditions in the marginal agroecologies, resource poor farmers often prefer to see immediate benefits of new technologies. In the CRV of Ethiopia, documentation with regard to short-term benefits and information regarding the agronomic and economic response, labor requirement, weed incidence, as well as ecological feasibility and viability of CA in maize production are lacking.

Therefore, we hypothesized that CT responds better than CA under similar water conservation management when practiced over short-term and that CA may be a potential alternative to CT when practiced over long-term. Farmers lacking sufficient number of oxen and female headed households (who due to cultural reasons and/or household loads can not till their farms) could be potential beneficiaries. The water conservation (capturing available rain water and retaining it for increasing water use efficiency by maize) management is principally aiming at improving volumetric soil moisture content to mitigating the impacts of rainfall variability – recurrent dry spells and droughts – in maize production. A single intervention may not increase maize production in marginal agro-ecology of the CRV of Ethiopia. In this current study, we investigated early maturing and drought tolerant maize variety (*Zea mays* L. var. Melkassa-II) under different tillage and water conservation management for its agronomic and economic responses. As an entry point, this study, therefore, examined the short-term (for two consecutive years) agronomic and economic responses from practicing CA and CT under similar water conservation management. Specifically, the effects of CT, MT, and ZT under mulching, no mulching and planting basin were evaluated according to: (1) agronomic response; (2) volumetric soil moisture content; (3) weed density; and (4) economic response as well as the potential and viability of CA over short-term practice.

2. Materials and methods

2.1. Description of study sites

The study sites were in Ziway and Melkassa in the CRV of Ethiopia (Fig. 1), which are located in the East Shoa Zone of Oromiya Regional State, Ethiopia. Ziway is located at 7°9′N latitude, 38°43′E longitude, at an altitude of 1642 m.a.s.l, 122 km south of Addis Ababa. Ziway receives a bimodal rainfall from April to October, with June–October as the main cropping season for the cultivation of early-maturing cereals and pulses. Risk-taking farmers also cultivate mid-maturing maize varieties in April, though it is affected by the cessation of rain in late May.

Melkassa is located at 8°4′N latitude, 39°31′E longitude and lies at an altitude of 1550 m.a.s.l. It is located 115 km south east of Addis Ababa. Melkassa receives a bimodal rainfall, with June–October as the main cropping season for cultivation of early-maturing cereals and pulses.

2.2. Farm characteristics

The central rift valley of Ethiopia has been identified as semiarid (Engida, 2000). Rainfall variability adversely affects agricultural production. There is a recurrent drought, dry spells and late onset and early cessation of rainfall. Serious moisture deficit in the growing seasons occurs, particularly around flowering and grain filling of maize, causing substantial yield reductions or even occasionally total harvest failure. This is a mixed farming system, where both livestock and crop farming are important agricultural practices. Cattle are important in the agricultural production system as they provide draught and threshing power, and manure to improve soil fertility and provide materials for fuel. Crop residues are used as fodder, particularly during dry seasons, as well as providing a source of domestic fuel. Mono-cropping of cereals – mainly maize (*Zea mays*), *Teff* (*Eragrostis tef*) and pulses – is a common practice in these areas. Maize is the predominant staple food crop for the rural population in the region. As in most places in Ethiopia, the region is characterized by wide open grazing after crop harvest (Belay et al., 2013; Kassie et al., 2013, 2014). The soil in the CRV is classified as Haplic Solonetz with a texture ranging between loamy sand to sandy loam (Itanna, 2005) based on FAO soil classification systems.

2.3. Experimental design and treatments

In the 2011 and 2012 cropping seasons (two succeeding years), field experiments on tillage and water conservation management were carried out at both sites. The experimental design was a split-plot with four replications. The main plots consisted of CT (four time oxen plowings), MT (one time oxen plowing during planting) and ZT (planting directly into the soil with a pointed stick (dibble stick)). Each main plot was split into three subplots: mulch, no mulch and planting basin. The planting basin (made by hand hoe) was of 0.40 m long, 0.15 m wide and 0.10 m deep. The treatments received 1.0 g DAP ($(NH_4)_2HPO_4$) per planting station (where seeds

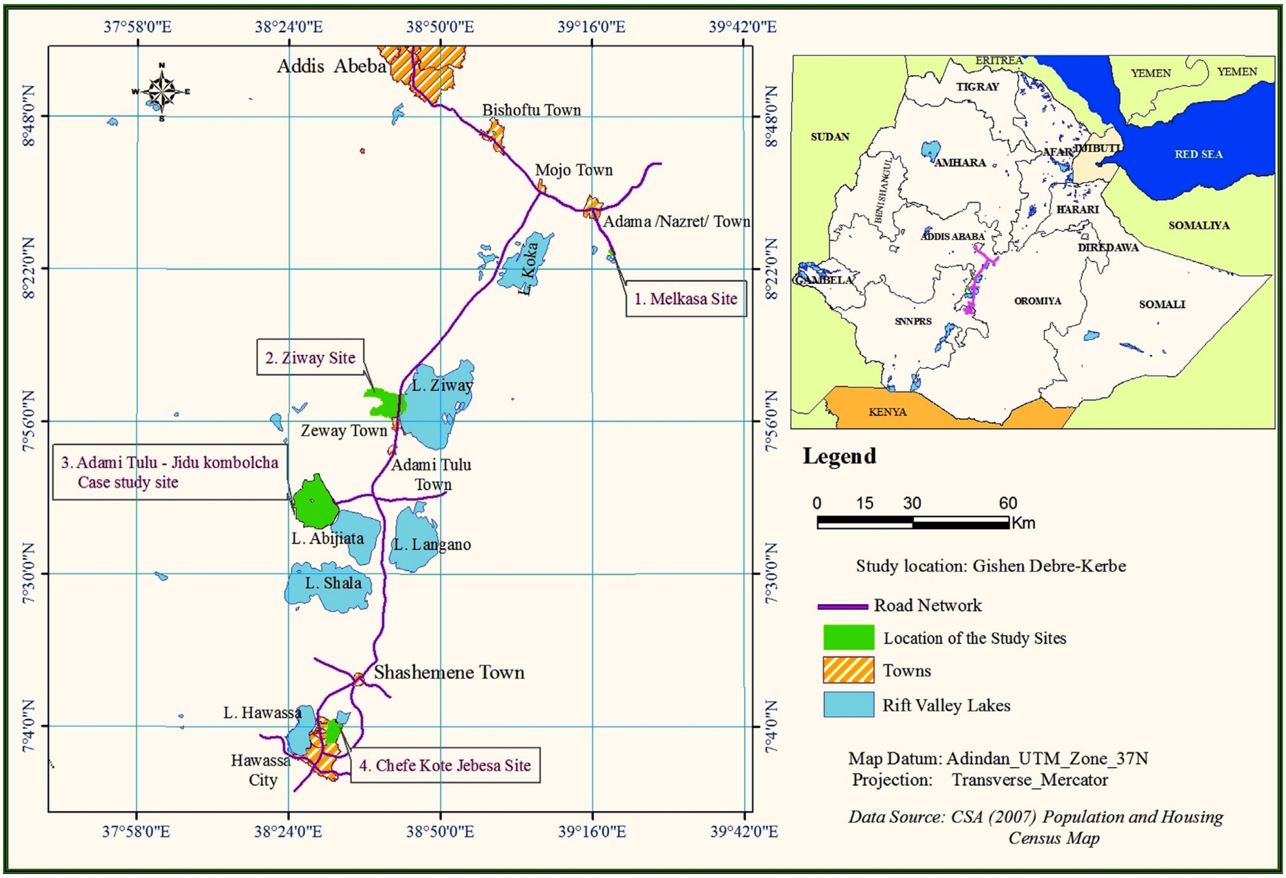

Fig. 1. Map showing the location of the study sites.

and fertilizer are placed adjacent to each other) at planting, which corresponds to 53 kg DAP ha^{-1}. One gram urea ($CO(NH_2)_2$) per planting station was also applied at knee height (40 days after planting). The plot size was 3.00 by 4.80 m (14.4 m^2). Each plot consisted of six rows with a spacing of 0.80 m between rows and 0.30 m between plants. The blocks were separated by a 1.5 m wide open space. The crop tested was maize (*Zea mays* L. var. Melkassa-II). The area for the experiment was uniformly treated before the experiment was established.

Maize stalk was applied as surface mulch to all mulched treatments, which is equivalent to 4 t ha^{-1} (approx. 60% soil cover), during the first season at both sites. During the first cropping season, maize stover was supplied from external fields. After the first harvest, the fields were fenced to retain maize residues until the next cropping season (June 2012). Permanent plots were used during the two years experimental period in order to study changes in soil moisture retention capacity as well as agronomic and economic responses. Weeds were controlled manually with a short hand hoe, commonly used in the areas.

2.4. Soil moisture measurement and rainfall data

The SM300 Soil Moisture Sensor with the Delta-T HH2 handheld Moisture Meter (data logger) was used to measure the volumetric soil moisture content (%), with ±2.5% accuracy. The sensor can measure over 0–50% volume water in the soil. The sensor/probe (51 mm) was inserted/buried into the surface and subsurface of the soil (0–15 cm, crop root zone). Accordingly, three soil moisture measurements were recorded from the central row of the mulched, no mulched, and basin treatments. The measurements were taken systematically at different intervals the following day after rain: first week after planting, flowering, and physiological maturity. The purpose of measuring volumetric soil moisture content was to estimate the effect of mulching and no mulching, and planting basin and tillage management on soil moisture content which depicts the plant available water in the soil.

The long-term climate data and that of the experimental seasons for Melkassa and Ziway sites were gathered from the closest meteorological centers located at Melkassa and Adami Tulu Agricultural Research Centers respectively.

2.5. Weed data and measurement

Weed count data (number m^{-2}) were recorded three and six weeks following planting, just prior to manual weeding. A one meter by one meter quadrat (1 m^2) was placed randomly in three places in each plot, resulting in a total sample area of 3 m^2 plot^{-1}. The counting was conducted three (first weeding) and fifth (second weeding) weeks after planting. Additionally, before flowering and seed setting, remaining weeds were slashed to reduce weed seed banks.

2.6. Soil sampling and laboratory analysis

Twenty four composite soil samples (6 treatments per replication) were randomly collected at the depth of 0–15 cm to determine the pre-experiment physico-chemical characteristics of the soil. The soil samples were collected one week before planting and fertilization in 2011. The pH was measured on 1:2.5 soil/water suspensions with a glass electrode pH meter, organic carbon was measured using wet oxidation methods (Wakley and Black, 1934) and TN by Kjeldahl procedure (Bremner and Mulvaney, 1982). Available phosphorus (Olsen) was determined according to the Olsen method (Olsen et al., 1954). Exchangeable calcium and magnesium were determined using atomic absorption photometer, while sodium and potassium were determined by flame photometry (Black et al., 1965). Cation exchange capacity was determined (Chapman, 1965). Soil texture analysis was done using Boycous hydrometric method (Black et al., 1965). Bulk density (BD) and total porosity (TP) were determined from twenty four undisturbed cores samples (0–15 cm soil depth) which were collected by core sampler (size 5.8 cm diameter and 3.7 cm height). The BD was then determined after drying the core samples in an oven at 105 °C, 24 h while the TP (%), the percentage of bulk volume of soil not occupied by solid particles, was determined from saturated soils (Nelson and Sommers, 1982).

2.7. Agronomic data and measurement

The agronomic data collected include percent pocket germination (two seeds were placed in each planting station to increase percent seed germination), seedling vigor (rated 1–5 where: 1 = poor, 2 = low, 3 = moderate, 4 = vigorous, 5 = very vigorous), lodging count, plant height (cm), and grain and stover yield (kg ha^{-1}). Plants fallen, inclined or with broken stalk were considered as lodging. Plant height (cm) was measured from the ground level to the base of the tassel for five randomly selected plants per plot. Stover weight was measured after sun drying the stover for nine days when no change in the stover weight was observed between consecutive measurements. Maize cobs were harvested, shelled, weighed, grain moisture measured and eventually corrected for moisture content at 12.5% by a multigrain digital moisture meter. Yield was extrapolated and then reported on a hectare basis. To avoid border effects, the agronomic data were collected from the four central rows, with a net plot size of 9 m^2.

Field observations were carefully recorded and informal discussions were held with farmers, development agents and government institutions to create awareness about the interventions and to identify challenges and opportunities for practicing CT and CA in the study sites.

2.8. Economic data and analysis

Standard enterprise budgeting techniques were used to estimate production costs and profitability. Total revenue (TR) was calculated based on grain yield and grain prices obtained from the local market. The local market grain price used was

Table 1

Physical and chemical properties of soils at Ziway and Melkassa, collected one week prior to the experimentation in 2011.

Site	Physical and chemical property											
	K	Ca	Mg	Na	CEC	TP	BD	pH	EC	OC	TN	Av. P
Ziway	2.42	25.10	4.35	7.47	34.74	25.30	1.01	8.40	0.17	3.21	0.25	18.20
Melkassa	2.30	15.19	3.60	0.43	26.40	25.63	1.13	7.42	0.16	1.70	0.14	19.20

Key: Exchangeable cations (potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na)) organic carbon (OC (%)) and total nitrogen (TN (%)), electrical conductivity (EC (ds m^{-1})), bulk density (BD (g cm^{-3})) and total porosity (TP (%)).

0.23 US$ kg^{-1} (1 US$ = 18.24 Ethiopian Birr (ETB)). Total variable cost (TVC) was estimated from labor and input cost. Labor cost was estimated from labor incurred for seedbed preparation, planting, fertilization, mulching, weeding, harvesting and threshing. Rental cost for oxen was obtained from farmers. Input cost was determined from the cost of fertilizers (DAP and urea) and seeds. Local market seed, DAP and urea prices per kilogram were 1.14, and 0.82 and 0.63 US$ respectively. Labor cost was estimated at 1.64 US$ $person^{-1}$ day^{-1} (30 ETB $person^{-1}$ day^{-1}). Locally, for one time ploughing of a hectare of land, the rental cost of a pair oxen including human labor is 10.96 US$ (at 200 ETB). For each treatment, the time spent for each activity (seedbed preparation, planting, fertilization, mulching, planting basin making, thinning, weeding, harvesting and threshing) was recorded. Time use for the different activities was observed in all the plots of the experiment for the two years across both sites. In addition, the time spent when farmers worked as a group on the plots was observed. The average for each treatment was calculated. Costs of seeds, fertilizers, harvesting and threshing were considered to be the same for all treatments. Family labor was used as the major source of labor to increase farmers' participation, knowledge and attitudes for easy use of the technologies.

Gross margin (GM) for each treatment was determined as the difference between TR and TVC. Finally, labor productivity (LP) of each treatment was estimated as a ratio between maize grain (kg ha^{-1}) and the total amount of labor required (day ha^{-1}).

2.9. Statistical analyses

The General Linear Model of the ANOVA of SAS System Version 9.3 of SAS Institute Inc. (SAS, 2011) was used to determine treatment effects on agronomic, weed density, volumetric water content and economic responses. Means comparisons were conducted using the least significant differences (LSD), established at 5% significance level (P-value < 0.05). The data was analyzed as a split plot. Only significant effects were discussed unless otherwise presented in the text. Descriptive statistics were used for the qualitative data obtained from field observation and informal discussions with stakeholders.

3. Results

3.1. Soil physical and chemical properties

Table 1 presents physical and chemical soil properties. The soils at Ziway had lower available phosphorous (P) and bulk density (BD) than the soils at Melkassa. There were slightly more favorable conditions in the chemical properties (electrical conductivity (EC), organic carbon (OC), total nitrogen (TN), exchangeable cations including potassium (K), sodium (Na), calcium (Ca) and magnesium (Mg), and cation exchange capacity (CEC) in Ziway soils than in Melkassa soils. The soils at both sites had moderately alkaline pH. The soil texture at Ziway was clay loam (40% sand, 32% silt and 28% clay) and that of Melkassa was loam (37% sand, 41% silt and 23% clay). Total porosity (TP) was similar in both sites. Based on FAO soil classification systems, Itanna (2005) classified the soil in the CRV with texture ranging from loamy sand to sandy loam as Haplic Solonetz.

3.2. Rainfall, waterlogging, and dry spells

Fig. 2 presented the cumulative rainfall (mm) at Ziway and Melkassa during the experimental period from first of June to November of 2011 and 2012. The average total annual rainfall at Ziway over the past 12 years ranged from 518 to 1002 mm (average 815 mm), with an average maximum and minimum air temperature of 28 °C and 13 °C respectively. The total amount of rainfall received over 2011/2012 and 2012/2013 was 598 and 856 mm respectively. The total amount of rainfall received during the experimental period of the same years (June–October) was 442 and 732 mm respectively, which constitutes 74% and 86% of the total annual rainfall respectively. The average relative humidity during the experiment was 60%. The average maximum and minimum air temperature during the same period was 28 °C and 14 °C. The average total annual rainfall for Melkassa over the past 12 years ranged from 548 mm to 1093 mm (average 877 mm), with an average maximum and minimum air temperature of 29 °C and 14 °C respectively. The total amount of rainfall received over 2011 and 2012 was 923 and 924 mm respectively. The total amount of rainfall received during the experimental period of these two years (June–October) was 685 and 822 mm respectively. The average relative humidity for the experimental period was 62%. The average maximum and minimum air temperature during the same period was 29 °C and 12 °C.

Across sites and years, frequent waterlogging with durations of 3–5 days was observed during early growth of maize in July and early August. The treatment ZT was particularly affected, as well as mulching and basin treatments. Waterlogging occurred mainly in July, between planting and maize knee height. Treatments with waterlogging had yellow leaves and stunted growth. There were also periods with dry spells during the season. No mulch treatments in CT were particularly affected by the dry spells.

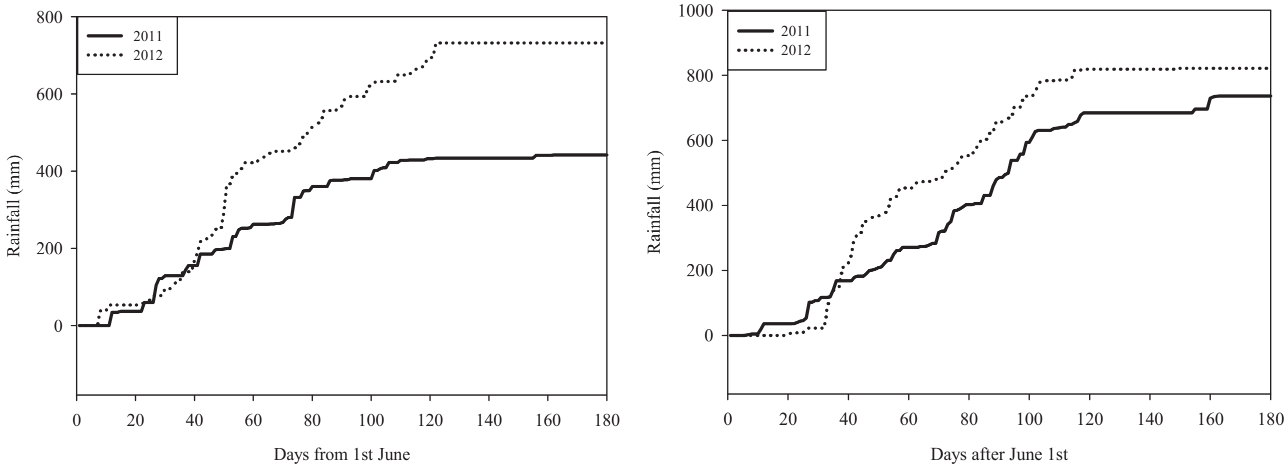

Fig. 2. Cumulative rainfall (mm) at Ziway (left) and Melkassa (right) during the experimental period from first of June to November of 2011 and 2012.
Source: The sources of the rainfall data for Ziway and Melkassa sites are Adami Tulu and Melkassa Agricultural Research Centers respectively.

Table 2
Average yield characteristics in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

	Ziway						Melkassa					
Treatment	PSG (%)	UF	SV	LC	PH (cm)	SCH	PSG (%)	UF	SV	LC	PH (cm)	SCH
CT	98.1a	3.7a	3.8a	2.3a	191.5a	47.3a	98.9a	3.8a	3.5a	2.1b	211.5a	47.5a
MT	97.4a	3.4a	3.7a	2.4a	184.4a	46.9a	98.3a	3.3b	3.4a	2.3b	206.0b	47.6a
ZT	95.6a	2.5a	2.5a	3.9a	175.9a	45.5a	94.6a	2.1c	1.8b	3.4a	200.6c	45.8a
LSD	3.05	1.19	1.69	4.83	22.07	2.55	5.71	0.38	1.02	0.51	2.58	2.60
Mulch	97.8a	3.8a	3.8a	2.1b	191.75a	47.2a	97.7a	3.7a	3.7a	2.1a	213.09a	47.5a
No mulch	96.4a	2.7b	2.7b	3.9a	178.71b	46.1b	96.7b	2.5c	2.8b	3.4a	198.89a	46.5a
Basin	97.0a	3.2ab	3.5ab	2.7ab	181.33b	46.5ab	97.4ab	3.0b	2.3c	2.3a	206.3a	46.8a
LSD	2.83	0.89	0.96	1.30	9.06	0.73	1.02	0.15	0.39	2.21	21.46	0.96

Means in the same column with same letter are not significantly different at P-value < 0.05.
Key: PSG (%): percent pocket seed germination; UF: uniformity; SV: seedling vigor; LC: lodging count; PH (cm): plant height and SCH: stand plant count; CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

The dry spells caused temporary wilting in the CT treatments without mulching. Dry spells ranging between 5 and 10 days were more frequent in Ziway (double the frequency) than in Melkassa. There were dry spells occurring at flowering and physiological maturity. Most of the dry spells ranged between 4 and 7 days. Cessation of rainfall was observed in September across years and sites (Fig. 2).

3.3. Effects of tillage and water conservation management on characteristics of yields

Unlike at Ziway, tillage management of CT and MT improved seedling uniformity, seedling vigor, lodging and plant height at Melkassa compared to ZT. The CT also improved seedling uniformity and plant height compared to the MT at Melkassa. At Ziway, among the water conservation management mulching improved seedling uniformity and vigor, lodging, plant height and plant stand at harvest compared to no mulching as well as plant height compared to planting basin. Mulching also improved percent pocket seed germination, seedling uniformity and vigor compared to no mulching and planting basin at Melkassa. Plant basin improved seedling uniformity and seedling vigor compared to no mulching at Melkassa (Table 2).

3.4. Effect of tillage and water conservation management on average maize grain and stover yields

Across locations and sites, average grain yield improved in the order of CT > MT > ZT. The CT increased average grain yield by 13–20%, and 44–55% over MT and ZT respectively across sites. Similarly, MT increased average grain yield by 27–30% over ZT across sites (Table 3).

Effects on stover yield followed the same trend as the grain yields. The average stover yield across years and sites was 8092, 7343 and 6250 kg ha^{-1} for CT, MT and ZT respectively.

Across locations and seasons, mulching improved grain yield over basin and no mulch. During the second season across locations, basin improved grain yield over no mulch (Table 3).

The effect on stover yield followed the same trend as the grain yields. The average stover yield across years and sites was 8118, 6534 and 7138 kg ha^{-1}, for mulch, no mulch and basin respectively. Overall, over locations and seasons, the interaction between tillage and water conservation management on the grain and stover yields was not significant.

3.5. Effect of tillage and water conservation management on average weed density

The weed suppression effect between tillage management was insignificant. At Melkassa, CT suppressed second weed density compared to MT and ZT, so did MT compared to ZT. Weed density tended to increase with ZT and no mulch as follow ZT > MT > CT and with no mulch > basin > mulch. Across sites and seasons, there was less weed infestation in the mulched plots. Mulching suppressed first weed density at Ziway and second weed density at Melkassa compared to basin and no mulch (Table 4). The interaction between tillage and water conservation management was not significant.

3.6. Effects of tillage and water conservation management on average volumetric soil water content

The effect of tillage management on volumetric soil moisture content (plant available water) tended to increase towards the late growth stage of maize at flowering and physiological maturity at Ziway. At Ziway ZT had higher soil moisture capturing capacity compared to CT at flowering and physiological maturity (Table 5). There was no significant effect of tillage management on soil moisture capturing capacity at Melkassa.

Similarly, the effect of mulching on volumetric water content tended to increase towards the end of the growing season (Table 5). Mulching was able to improve soil moisture content more than no mulch and planting basin at planting, flowering and physiological maturity at Ziway. At Ziway, planting basins were also possible to improve soil moisture content more than no mulch at flowering and physiological maturity. At Melkassa, mulching was able to improve soil moisture content at physiological maturity.

Table 3
Average maize grain yield (kg ha^{-1}) in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

TM	Ziway		Melkassa		WCM	Ziway		Melkassa	
	2011	2012	2011	2012		2011	2012	2011	2012
CT	5356a	6419a	5547a	6027a	Mulch	4847a	6804a	4743a	5911a
MT	4544b	5860b	4396b	5259b	No mulch	4171b	4741c	4131b	4517c
ZT	3358c	4816c	3195c	4248c	Basin	4239b	5550b	4265b	5106b
Mean	4419	5698	4379	5178	Mean	4419	5698	4379	5178
LSD	499	432	299	482	LSD	357	394	262	320

Means in the same column with same letter are not significantly different at P-value < 0.05.
Key: TM: tillage management; WCM: water conservation management; CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

Table 4
Average weed density (number m^{-2}) in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

TM	Ziway		Melkassa		WCM	Ziway		Melkassa	
	FWD	SWD	FWD	SWD		FWD	SWD	FWD	SWD
CT	130a	48a	24a	18c	Mulch	100b	30a	17a	15b
MT	148a	54a	33a	22b	No mulch	170a	70a	43a	27a
ZT	160a	67a	45a	27a	Basin	168a	69a	42a	24a
Mean	146	56	34	22	Mean	146	56	34	22
LSD	34.41	20.75	35.17	3.10	LSD	57.52	63.53	31.72	5.08

Means in the same column with same letter are not significantly different at P-value < 0.05.
Key: TM: tillage management; WCM: water conservation management; FWD: first weed density; SWD: second weed density; CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

Overall, soil moisture capturing capacity tended to be higher in ZT and MT and mulch treatments. The variation in moisture retention capacity among treatments was higher in Ziway, with lower rainfall and more dry spells, than in Melkassa. The interaction between tillage and water conservation management in volumetric water content was not significant.

3.7. The economic assessments of tillage and water conservation management

Gross margin increased with CT compared with other tillage practices as follow CT > MT > ZT (Table 6). Rental cost increased with CT as follow CT > MT > ZT; whereas, labor demand for weeding increased with ZT compared with other tillage practices as follow ZT > MT > CT. Farmers on average spent 40, 44 and 54 days ha^{-1} of labor with CT, MT and ZT respectively.

4. Discussion

4.1. Tillage management and maize agronomic responses

Under similar water conservation management, CT was able to improve maize agronomic responses over CA. The performance in yield characteristics in the CA plots were generally lower than the CT plots, for instance at Melkassa. The CT increased average grain yield by 13–20% and 44–55% over MT and ZT respectively across sites. Similarly, MT improved average grain yield by 27–30% over ZT across sites. Field observations indicated rigorous waterlogging (temporary) and yellow leaved and subtly grown maize stands in MT and ZT plots. Moreover, there was a faintly increasing weed tendency in the same plots. Therefore, the generally lower performance in yield characteristics, higher waterlogging and slightly increasing weed infestation and the short duration of the experimentation might be the most likely reasons for the yield depression in the MT and ZT plots. Several reports indicated waterlogging under higher rainfall season in CA causes yield depression (Giller et al., 2009; Rockström and Barron, 2007; Rusinamhodzi et al., 2011). Absence of tillage can result in higher run-off and lower infiltration leading to lower yields (Tadesse et al., 1996). Biazin and Sterk (2013) also reported temporary waterlogging in maize fields the central rift valley in Ethiopia. Maize is moderately sensitive to waterlogging that reaches anaerobiosis point when the root zone soil moisture status is at about 5–10% below the saturation point (FAO, 2009). In contrast to CA, no waterlogging problem was observed under conventional tillage, which signifies the reasons for increasing the frequency of tillage for crop production in Ethiopia. Temesgen et al. (2008) reported similar reasons in Ethiopia for increasing ploughing frequency to improve infiltration, minimize run-off and reduce evaporation of water from soil surface. Increased weed competition and waterlogging (under poor drainage conditions) can impact crop production negatively in CA (Giller et al., 2009) when practiced over short-term. Conservation tillage reduces crop yields through limiting soil physical properties, increasing weeds and decreasing fertilizer efficiency (Murillo et al., 1998). According Giller et al. (2009), despite the fact that CA can result in yield benefits in the long-term, yield losses or no yield benefits are likely in the short-term practice (which may need up to 10 years). Yet several studies have also found higher maize yields in conservation than conventional tillage from experiments conducted over three to four years in Ethiopia (Ito et al., 2007; Rockström et al., 2009) and 3–10 years in Malawi (Ngwira et al., 2012). Several other reports indicated that it takes some years before the yields benefits become evident in CA practices. Increased retention of mulch, soil moisture, improved soil structure and biotic activity could increase long-term crop yields in conservation tillage (Fowler and Rockström, 2001; Ito et al., 2007).

4.2. Water conservation management and agronomic responses

Irrespective of tillage management, mulching improved most of the agronomic responses far more than no mulching. In the central rift valley of Ethiopia, despite the high intra and inter seasonal variability in rainfall (Biazin and Sterk, 2013; Kassie et al., 2013, 2014), maize production has always been considerably affected by late on setting and early cessation of rainfall in the study sites which usually happens during flowering and/or physiological maturity (Biazin and Sterk, 2013). In this study, the better soil moisture condition under mulching is the most likely condition to improve most of the agronomic parameters; namely seedling vigor,

Table 5
Average volumetric water content (%) in the 0–15 cm soil depth in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

Site	Growth stage	TM				WCM			
		CT	MT	ZT	LSD	Mulch	No mulch	Basin	LSD
Ziway	Planting	31.1a	30.6a	32.0a	4.3	33.6a	29.0b	30.9b	2.3
	Flowering	27.0b	27.9ab	28.9a	1.9	30.8a	25.5c	27.4b	1.3
	Maturity	26.3b	26.5ab	26.9a	0.5	27.4a	25.9c	26.5b	0.3
Melkassa	Planting	26.9a	26.5a	26.6a	3.9	28.5a	24.5a	26.9a	5.1
	Flowering	32.8a	33.3a	32.8a	2.4	35.3a	30.8a	32.8a	9.3
	Maturity	27.1a	27.4a	27.6a	1.4	28.3a	26.7b	27.1b	0.5

Means in the same row with same letter are not significantly different at P-value < 0.05.
Key: TM: tillage management; WCM: water conservation management; CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

Table 6
Total revenue, total variable costs, gross margin and labor productivity (in US$) in response to tillage and water conservation management, over the 2011 and 2012 cropping seasons at Ziway and Melkassa.

Item	Unit price (US$)	CT				MT				ZT			
		Mulch	No mulch	Basin	Mean	Mulch	No mulch	Basin	Mean	Mulch	No mulch	Basin	Mean
1. Revenue													
Maize grain (kg ha^{-1})		6375	5605	5534	5838	5616	4475	4954	5015	4740	3091	3883	3905
Total revenue (US$ ha^{-1})	0.23	1466	1289	1273	1343a	1292	1029	1139	1153b	1090	711	893	898c
2. Input cost													
Maize seed (US$ ha^{-1})	1.14	30	30	30	30	30	30	30	30	30	30	30	30
DAP (US$ ha^{-1})	0.82	44	44	44	44	44	44	44	44	44	44	44	44
Urea (US$ ha^{-1})	0.63	34	34	34	34	34	34	34	34	34	34	34	34
Total input cost (US$ ha^{-1})		107	107	107	107	107	107	107	107	107	107	107	107
3. Labor use (day ha^{-1})													
Weeding		4	9	6	6c	7	15	12	11b	14	23	19	19a
Others (planting, mulching, fertilization, etc.)		31	28	44	34	30	26	45	34	31	27	47	35
Total labor (day ha^{-1})	1.64	35	37	50	40	37	41	57	44	45	50	66	54
Total labor cost (US$ ha^{-1})		57	61	82	66	61	67	93	72	74	82	108	89
Rental cost (US$ ha^{-1})	10.96	44	44	44	44	11	11	11	11	0	0	0	0c
Total variable costs (US$ ha^{-1})		209	212	233	217a	179	186	212	190a	181	189	216	196a
4. Returns													
Gross margin (US$ ha^{-1})		1257	1077	1040	1126a	1113	843	927	963b	909	522	677	702c
Labor productivity (kg day^{-1})		182	151	115	146a	152	109	93	114b	105	62	67	77c

Means in the same row with same letter are not significantly different at P-value < 0.05.
Key: CT: conventional tillage; MT: minimum tillage; and ZT: zero tillage.

uniformity, plant height, lodging, and plant population at harvest under mulching. These improved agronomic characteristics would have positive effect on overall maize yield. As a result, mulching increased average grain yield by 23–33% and 14–19% over no mulch and planting basin respectively. Previous studies indicated that mulching increased biomass and grain yield of maize by 54 and 56% respectively (Tenaw et al., 2002) in the moisture stressed areas in Ethiopia. Several previous studies indicated that mulching increased yields in maize (Adeniyan et al., 2008), *Teff* (Tulema et al., 2008) and grains (Thomas et al., 2007) under conservation agriculture.

Therefore, the overall promising performance of mulching over the short-term, particularly during the second season across sites, is suggestive of its higher long-term potential in improving maize production in the region. During the second season across sites, mulching was able to improve maize yields over no mulching and planting basin. This is favored by the finding that productivity benefits in CA accumulate over time as mulching gradually improves the physico-chemical and biological properties of soils (Erenstein, 2003). As a result, regardless of tillage management, mulching appears to be an appropriate method for mitigating the negative impact of the frequent inter and intra seasonal dry spells on maize yields in the region. It may importantly contribute towards achieving climate-resilient and sustainable maize production in the region. However, due to the open grazing on fields after harvest, currently mulching cannot be practiced on open fields. Therefore, for farmers who would like to operate on fenced small fields around homesteads, mulching could be the best option. Yet there is a need to study how to better incorporate crop residues as mulching into maize production in the region.

Compared to no mulching, the yield benefits of basin become higher during the second season across sites. Planting basins were also able to capture more water than no mulch at flowering and physiological maturity at Ziway. Planting basins may therefore be an option for farmers lacking oxen and operating higher dry spells and droughts. There is a tradition of planting early-maturing maize on fenced small plots around homesteads in order to offset food shortages during the pre-harvest, and to generate income from selling green cobs. The CA with basin has been widely promoted for resource poor farmers in Southern Africa (Nyamangara et al., 2013). The cost of oxen rental in the study sites is high (11 US$ ha^{-1} for one time passage) and is a pressing challenge for farmers lacking sufficient draft power. Farmers without oxen should work for oxen owners for 2–3 days in return for hiring oxen for one day. Another option for such farmers is to practice sharecropping or renting out farm lands to others. It was reported that permanent basins decreased oxen requirement under CA in northern Ethiopia (Nyssen et al., 2011).

4.3. Tillage and water conservation management and volumetric soil moisture content

Although the agronomic responses were lower, CA plots tended to retain more soil moisture towards later growth of maize than CT in Ziway, with lower seasonal rain fall and more dry spells. This result could, therefore, suggest the long-term potential of CA practices as an alternative system in maize production operating under recurrent dry spells and drought occurring in the study sites. Thierfelder and Wall (2009) also reported higher soil moisture levels throughout the season in CA than in conventional tillage. In addition, the same authors suggest that CA has high potential for increasing rain water productivity and; therefore, to reduce the risk of crop failure, particularly during the later growth stage of maize in Zambia.

Among the water conservation management, mulching became so inconsistent in its moisture conservation potential across sites. Compared to no mulching, mulching was able to conserve more volumetric soil moisture for the entire growth period at Ziway. Mulching improves soil moisture and enhances water infiltration (Adeniyan et al., 2008; Thomas et al., 2007; Tulema et al., 2008). Ziway had relatively lower seasonal rainfall as well as more dry spells and intra and inter-seasonal rainfall variability. Mulching was also able to retain more soil moisture at physiological maturity at Melkassa, one of the critical stages in maize growth demanding considerable amount of soil moisture. Mulching is therefore likely to work well in areas with more dry spells and rainfall variability. It might have improved infiltration and minimized water evaporation in soil (Rockström et al., 2009). The higher capacity of mulching in conserving more water at planting, flowering and physiological maturity, critical stage in maize growth demanding high water, in particular will have remarkable importance in making maize production more resilient to the recurrent rainfall variability. In the semiarid regions, mulching was found to be effective in reducing risk of crop failure due to better water retention capacity of available rainfall (Scopel et al., 2004). Planting basin tended to increase soil moisture content.

4.4. Water conservation management and weed density

Mulching was inconsistent in its weed suppression effects. It was also able to suppress the first weed density at Ziway and the second weed density at Melkassa. Overall, weed density tended to decline with mulching across sites. The lower weed density under mulching might have reduced the competition of weeds for soil moisture and nutrients and have contributed to the higher yield under mulching. The suppression of weed incidence by mulching corresponds with the results reported on *Teff* production in Ethiopia (Tulema et al., 2008). Effective weed suppression by mulch in maize production has been documented (Essien et al., 2009; Uwah and Iwo 2011). Therefore, besides minimizing financial outlays for farmers, weed control through mulch appears to be eco-friendly as the need to use herbicides is reduced. This could also help farmers free some labors investing on other farm and socioeconomic activities. Planting basins tended to reduce weed density but tended to increase maize yields indicating its high potential particularly for farmers lacking oxen. Conservation tillage with basin has been widely promoted in Southern Africa to be used by resource-poor farmers with limited access to draft power (Nyamangara et al., 2013). Nyssen et al. (2011) reported permanent basins increasing the need for weeding in the first years under conservation tillage in Northern Ethiopia.

4.5. Tillage and water conservation management and economic response

The CT increased labor productivity by 28 and 90% compared with MT and ZT respectively. MT increased labor productivity by 48% compared with ZT. The CT became the most profitable, increasing gross margin by 17 and 60% over MT and ZT respectively. The MT increased gross margin by 37% compared with ZT. Tulema et al. (2008) also indicated that zero tillage resulted in lower gross margin in *Teff* production than conventional tillage. MT yielded an average gross margin and labor productivity, between CT and ZT. The cost for seedbed preparation was lower in MT and ZT, but weeding costs constituted a major source of the increased costs of production in MT and ZT. As a result, farmers spent a higher number of days in MT and ZT (with the highest weed density) than in CT. The higher weeding costs in MT and ZT might attribute to the fact that herbicides were not used in this study. Tulema et al. (2008) report minimum tillage improves farm productivity by reducing tillage costs and allowing partial replacement of oxen with cows. Thomas et al. (2007) also reported reduction in costs to tillage operations in conservation agriculture. Lower cost for seedbed preparation is the immediate benefits of conservation tillage (Fowler and Rockström, 2001). A reduction in cost of production under conservation tillage practices than conventional tillage (Govaerts et al., 2009) when herbicides are used. Although higher input costs for herbicides were incurred, farmers got better agronomic benefits and income from conservation tillage experiments conducted over three years (1999–2003) season under maize production in Ethiopia (Ito et al., 2007). In conservation tillage, several investigators indicated that weed control is often laborious and costly suggesting a higher demand for herbicide use than manual weeding (Wall, 2007); use of herbicides substantially decreases the hand-weeding labor costs (Tulema et al., 2008); and excluding herbicides from conservation tillage increases the labor requirements for weeding (Giller et al., 2009; Ngwira et al., 2012). The exclusion of herbicide in this study assumes higher costs for purchasing herbicides, hiring herbicide application equipment or sprayers, accessibility, and negative environmental impacts.

Regardless of tillage management, mulching reduced weed density and labor costs for weeding; which complies to previous studies (Thomas et al., 2007; Tulema et al., 2008). The lower cost for seedbed preparation is an immediate benefit of CA (Fowler and Rockström, 2001). This current study also found similar results where the rental cost for seedbed preparation was 75% less in MT compared with CT. Owing to the reduction in tillage costs and economic responses, MT may be an interesting option for farmers with a shortage of oxen and in female households who due to either cultural reasons or house loads cannot use intensive tillage. There is high rental cost for oxen in Ethiopia (Aune et al., 2001) and conventional tillage is expensive to farmers without oxen (Tulema et al., 2008). This indicates that farmers who lack oxen could benefit from practicing CA due to reduction in the requirement for oxen.

Mulching is a difficult option in the central rift valley due to low crop biomass, alternative use of mulch as livestock fodder, free grazing, and the low awareness of the importance of recycling crop residues. In this regard, shortage of crop residues, prioritization of crop residues for livestock fodder and lack of sufficient information as major concern that virtually challenge adoption of conservation tillage practice in most SSA countries (Giller et al., 2009), and lack of farmers' awareness of CA benefits (Araya et al., 2012; Kassie et al., 2009) in Ethiopia. The wide free grazing after crop harvest in the region remains a major challenge to practicing mulching on open fields even under high yields. According to Valbuena et al. (2012) in areas with relatively high feed pressure, there is need to have a strategy of increasing biomass production and developing alternative sources to alleviate the opportunity cost of leaving crop residues as mulch. The abandonment of stubble grazing which has environmental benefits like soil conservation is a pre-requisite for implementing resource-conserving technologies in Ethiopia (Oicha et al., 2010).

5. Conclusions

The results from the two years of field experiments have demonstrated that conventional tillage provides greater agronomic and economic benefits compared with minimum tillage and zero tillage. Conventional tillage improved maize yields, gross margin and labor productivity far more than minimum tillage and zero tillage. The most likely reasons for the yield depression and lower economic response in CA can be related to the generally lower performance in yield characterisics, temporary waterlogging, increasing tendency of weed density and short duration of experimentation. Minimum tillage performed much better than zero tillage and it can be a potential option for farmers lacking sufficient oxen for plowing and for female headed households. Regardless of tillage management, mulching improved agronomic and economic benefits compared to no mulch and planting basins. Planting basins also tended to perform higher than no mulching and proved to show its potential. Despite the inconsistency, mulching was able to improve volumetric soil moisture content for efficient plant use, and reduced weed density and the labor requirement for weeding. However, owing to free grazing on open fields after crop harvest (realized from field observations and interaction with local communities and administration), mulching seems feasible only on small plots around homesteads where famers have fenced plots for growing early-maturing maize. Despite lack of easy access to oxen principally during peak time of planting, the oxen rental cost for intensive tillage is expensive to farmers lacking sufficient oxen and having financial constraints. Intensive tillage is also a challenge to female headed households who due to either cultural reasons or house loads cannot till their farms. Considering the short-term agronomic and economic potential of conservation agriculture (particularly minimum tillage) and the existing challenges in conventional tillage, we suggest further study (based on long-term) on how to sustainably integrating conservation agriculture to the widely practiced conventional tillage for the potential beneficiaries. On other end, sustainable integration of appropriate water conservation management (mulching) and adapting maize varieties (early maturing and drought tolerant maize) into the farming system in the central rift valley might further promote the existing traditional methods (Shilshalo and ridging) and make maize production more resilient to rainfall variability to improve food security and farmers livelihoods in the region.

Acknowledgements

This research was funded by the Norwegian Ministry of Foreign Affairs through the institutional cooperation between Hawassa University, Ethiopia and the Norwegian University of Life Sciences. The authors are sincerely grateful to Dr. Andargachew Gedebo for his unreserved help during the entire period of field work. Melkassa Agricultural Research Center and, particularly, Dr. Dagne Wagary deserve great thanks for recommending the proper maize variety and providing seeds, in addition to his encouragement, guidance and field visits. Mrs. Beyene, Yakob, Kaleb, Feyisso and partner farmers also deserve special thanks for their unreserved assistance during field work and in managing the experimental plots. Local farmers and agriculture development agents provided useful insights and assistance to the researchers. We are grateful to the district agriculture and rural offices for their generous hospitality and support.

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