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Conservation agriculture-based *Zea mays* (maize)-*Phaseolus vulgaris* (common bean) cropping systems in South Central Ethiopia

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Conservation agriculture (CA) is defined as sustainable agriculture production system comprising a set of farming practices. The experiment was conducted at three districts from 2011 to 2016 at five farmers' field they considered as replicate. The experiment consisted of five treatments (continuous sole maize, maize bean rotation, maize-bean inter-cropping, bean rotation under CA and farmer practice). Maize yield and yield related traits and soil water data were collected from each site. Soil moisture content under CA practices was higher than the farmer practice. At East-Badawacho and Meskan grain yield was higher by 4 and 8% in CA compared with farmer practice, respectively. Maize bean rotation and sole maize under CA out yielded the farmer practice by 13 and 4%, respectively but inter-cropping had 5% lower grain yield. At Hawassa-Zuriya, CA maize bean rotation had higher yield than farmer practice in 2011 and 2013. Maize-bean inter-cropping, maize bean rotation and sole maize under CA had 10, 8 and 6% higher grain yield than farmer practice, respectively. Common bean grain yield from bean rotation under CA had 2799, 2908, and 3226 kg ha^{-1}, from inter cropping bean grain yield of 817, 1065 and 927 kg ha^{-1} obtained at East-Badawacho, Hawassa-Zuriya and Meskan districts, respectively. Generally, CA cropping systems had drought stress reduction potential and greater yields compared with farmer practice.

Key words: Farmer-practice, sole-maize, rotation, inter-cropping, rift-valley.

INTRODUCTION

In Africa, the agriculture sector dominated by small-scale farmers who use traditional methods and tools of production (Musa, 2015). Agricultural production in the semi-arid regions of Sub-Saharan Africa (SSA) is

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challenged by many risk factors and high vulnerability of poorly resourced farmers (Solomon, 2018). Key sources of risk in agriculture include climate, socio-economic factors, soil degradation, and poorly developed markets (Kassie et al., 2013). Agriculture continues to be the major sector in Ethiopia's economy, with cereals playing a critical role. Maize is Ethiopia's largest cereal commodity in terms of total production, acreage, and the number of farm holdings (Rashid et al., 2010). Rainfall in Ethiopia is seasonal with high spatial and temporal variability. In the Central and Southern Rift Valley of Ethiopia rainfall pattern is bimodal and starts with the spring rains or Belg during the months of March to May and the summer rain or Kiremt extends from June to September (Solomon, 2018). Under conventional practice, soil erosion is one of the principal environmental problems in Ethiopia resulting in decreasing productivity of farmlands (Hurni, 1987). About 2 million hectares of land in Ethiopia have been severely degraded (Shiferaw, 2005). In Ethiopia the major causes of low productivity of the systems were lack of inputs and draft power and equipment, soil nutrient depletion, natural resources degradation, soil erosion, floods uncertain (drought), post-harvest management problems, unsustainable cropping systems, emerging new insect pest and diseases (Ellis-Jones et al., 2013; FAO, 2017; Lunt et al., 2018; MoANRD, 2018).

Conservation agriculture (CA) aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. It contributes to environmental conservation as well as to enhanced and sustained agricultural production. Conservation agriculture is a set of practices that leave crop residues on the surface which increases water infiltration and reduces erosion (Hobbs et al., 2008). Thus, residue levels alone do not adequately describe all CA practices. The importance of conservation agriculture is to conserve time and fuel; moreover, it improves earthworms, soil water, soil structure and increases soil nutrient contents as well as increasing water infiltration (Hobbs et al., 2008). It contributes to environmental conservation as well as to enhanced and sustained agricultural production. No-tillage practice minimizes soil organic matter losses and is a promising strategy yield to maintain or even increase soil carbon and nitrogen stocks (Bayer et al., 2000). Surface mulch helps reduce water losses from the soil by evaporation and also helps moderate soil temperature and promote biological activity and enhance nitrogen mineralization, especially in the surface layers (Hatfield and Pruegar, 1996; Hobbs et al., 2008). Infiltration of water under long-term (8-10 years) conservation tillage with residue retention was higher compared to conventional tillage on a grey cracking clay and a sandy loam soil in South-Eastern Australia (Bissett and O’Leary, 1996).

Rotation is cultural control of plant diseases from an historical view (Howard, 1996). The rotation of different crops with different rooting patterns combined with minimal soil disturbance in zero-till systems promotes a more extensive network of root channels and macrospores in the soil, and this helps in water infiltration to deeper depths (Hobbs et al., 2008). Rotations increase microbial diversity, and the risk of pests and disease outbreaks from pathogenic organisms is reduced (Leake, 2003). The benefits of CA especially when cereals are rotated with leguminous crops increase over time, suggesting that there are improvements in soil structure and fertility (Thierfelder et al., 2012).

Inter-cropping is a type of mixed cropping and defined as the agricultural practice of cultivating two or more crops in the same space at the same time. It increases in productivity per unit of land via better utilization of resources, minimizes the production risks, and stabilizes the yield (Ananthi et al., 2017). Inter-cropping of cereals with legumes has been practiced in tropics (Tsubo et al., 2005) and rain-fed areas of the world (Agegnehu et al., 2006; Dhima et al., 2007). Its benefits include soil conservation (Ananthi et al., 2017), weed control (Ananthi et al., 2017; Banik et al., 2006), and yield increment (Chen et al., 2004). In the southern part of Ethiopia, maize-common bean intercropping is an integral part of the cropping system as small-holder farmers expect better yield and weed suppression (Getahun and Tenaw, 1990), and provides balanced diet compared to the predominant cereal monoculture and gives high total productivity compared to sole crops of bean and maize (Walelign, 2014; Workayehu, 2014). There is a higher performance of maize bean rotation and maize bean inter-cropping under CA compared with continuous sole maize under CA and farmer practice (Liben et al., 2017). Similarly, higher maize grain yield from maize soybean rotation and maize soybean intercropping compared with sole maize under CA was reported (Liben et al., 2018). Better performance of relay cropping using maize and legumes under CA compared with the control sole maize and other inter cropping practices has also been reported (Daniel, 2019). Legumes, such as common vetch, common bean and cowpea are extensively used in inter-cropping with cereals (Daniel, 2019; Liben et al., 2017; Yilmaz et al., 2008), finger millet with maize (Nath, 2016), wheat with soybean (Sandler and Kelly, 2016), and maize with Soybean (Liben et al., 2018).

Under this study, the research questions were (1) which cropping systems performed best under CA compared to conventional practice and (2) which tillage practices conserves more soil water? The study was undertaken to (1) evaluate and compare maize bean cropping systems under CA and with sole maize under conventional practice, (2) to assess soil moisture content of different cropping systems and (3) assess the advantage of cropping systems under CA for reduction to risks from crop failure compared with conventional practice.

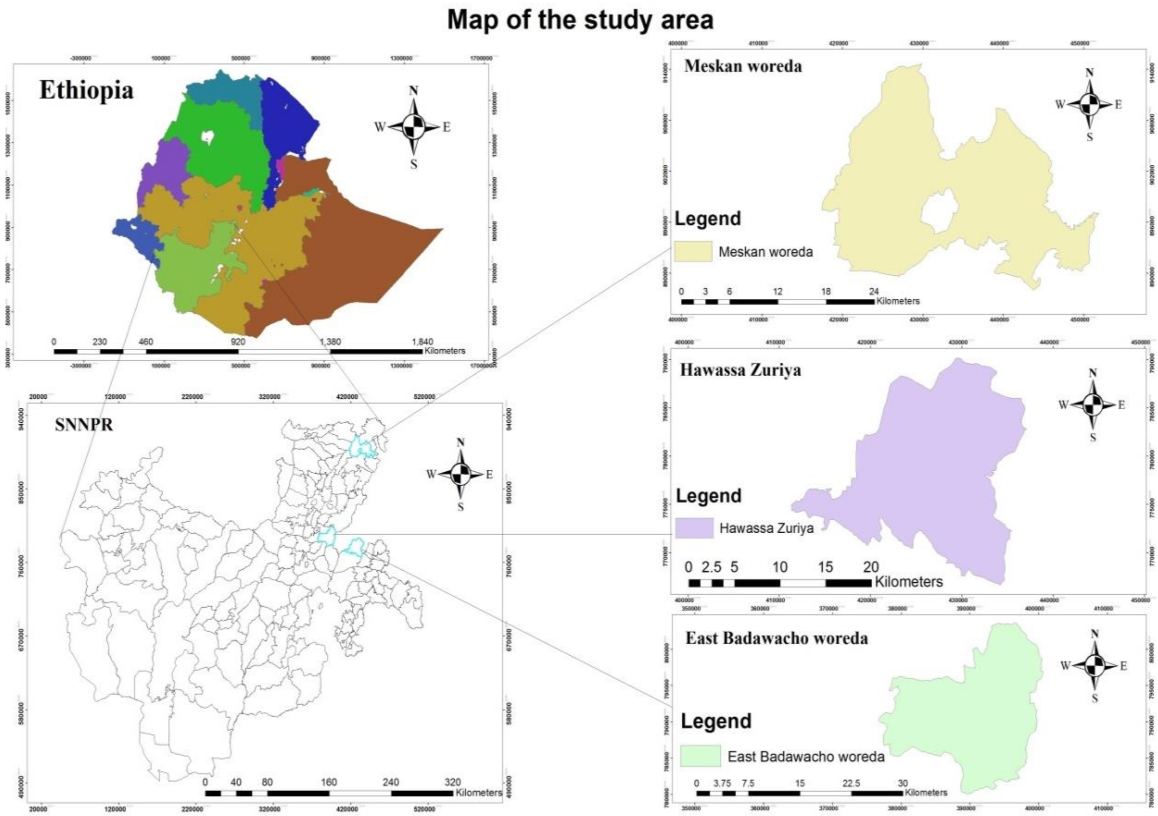

Figure 1. Map of the study area.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted at East-Badawacho (1788 masl, 037° 41ʹ 02 E, 07° 05ʹ 34ʺ N), Meskan (1839 masl, 038° 29ʹ 22ʺ E, 08° 04ʹ 53ʺ N) and Hawassa-Zuriya (1696 masl, 038° 23ʹ 22ʺ E, 07° 02ʹ 43ʺ N) districts farmers' fields during the period between 2011 and 2016 cropping seasons under rain-fed in the Southern Ethiopia (Figure 1). The common soil types at east Badawacho, Meskan and Hawassa-Zuriya are black basaltic soils (Vertisols), eutric Cambisols and vitric Andosols, respectively (Addise, 2014; Getahun et al., 2014; Lemma et al., 2015). These areas are characterized by bimodal rainfall received between March and September. The cumulative annual rainfall ranges between 872 and 1322 mm at East-Badawacho, 815 and 1346 mm at Meskan, and 900 and 1400 mm at Hawassa-Zuriya (TAMSAT). These areas are characterized by erratic rainfall distribution. The daily and cumulative monthly rainfall for sites is as shown in Figures 2 to 4.

Treatments

A trial comprising four cropping systems: continuous maize (CSM), maize-bean rotation RMB), bean-maize rotation (RBM), and maize-bean intercropping (MBI); all under conservation agriculture (CA) and continuous maize (FP) under farmers' practice were established at five farmers' field at each site.

For treatments under CA, narrow rows were opened with a hand-hoe to a depth of about 10 cm to place seeds and basal fertilizer application without prior tillage of the soil and retention of all the maize and bean crop residue produced the previous season as surface mulch. The conventional tillage practice or farmer practice was cultivated similar to the traditional farmers' land preparation practice for maize at each district. Land was prepared by conventional ploughing with an ox-drawn traditional plough called Maresha (ploughed the land 2 - 4 times depending on the soil types) before planting (Temesgen et al., 2009). The depth of the first ploughing ranges from 5 to 8 cm while with the last pass up to 20 cm depth could be attained.

Crop husbandry

Maize was planted at a spacing of 0.75 m between rows and 0.30 m between hills, and common bean was planted at a spacing of 0.40 m between rows and 0.1 m between hills. Each plot consisted of 13 rows of 10 m long (100 m^2 area). Two seeds were planted per hill and later thinned to one seedling upon stand establishment to maintain 44,444 plants ha^{-1} for maize and 250,000 plants ha^{-1} for common bean.

All treatments received fertilizer rates recommended: 110 kg N and 46 kg P_2O_5 ha^{-1} for maize and 46 kg P_2O_5 and 37 kg of N ha^{-1} for common bean. For maize, all the phosphorous and a third of N was applied as basal dose; while two-third N was side-dressed at 35 days after emergence. For common bean, all the fertilizer was applied at planting. Maize (cv BH-543 (154 days maturity)) and common bean (cv Hawassa Dume (102 days maturity)) varieties, were used in all years. In the maize-bean intercropping treatment, bean was planted at the same time as maize, between maize rows.

The treatments managed through conservation agriculture were sprayed with a broad-spectrum systemic herbicide (glyphosate) 10

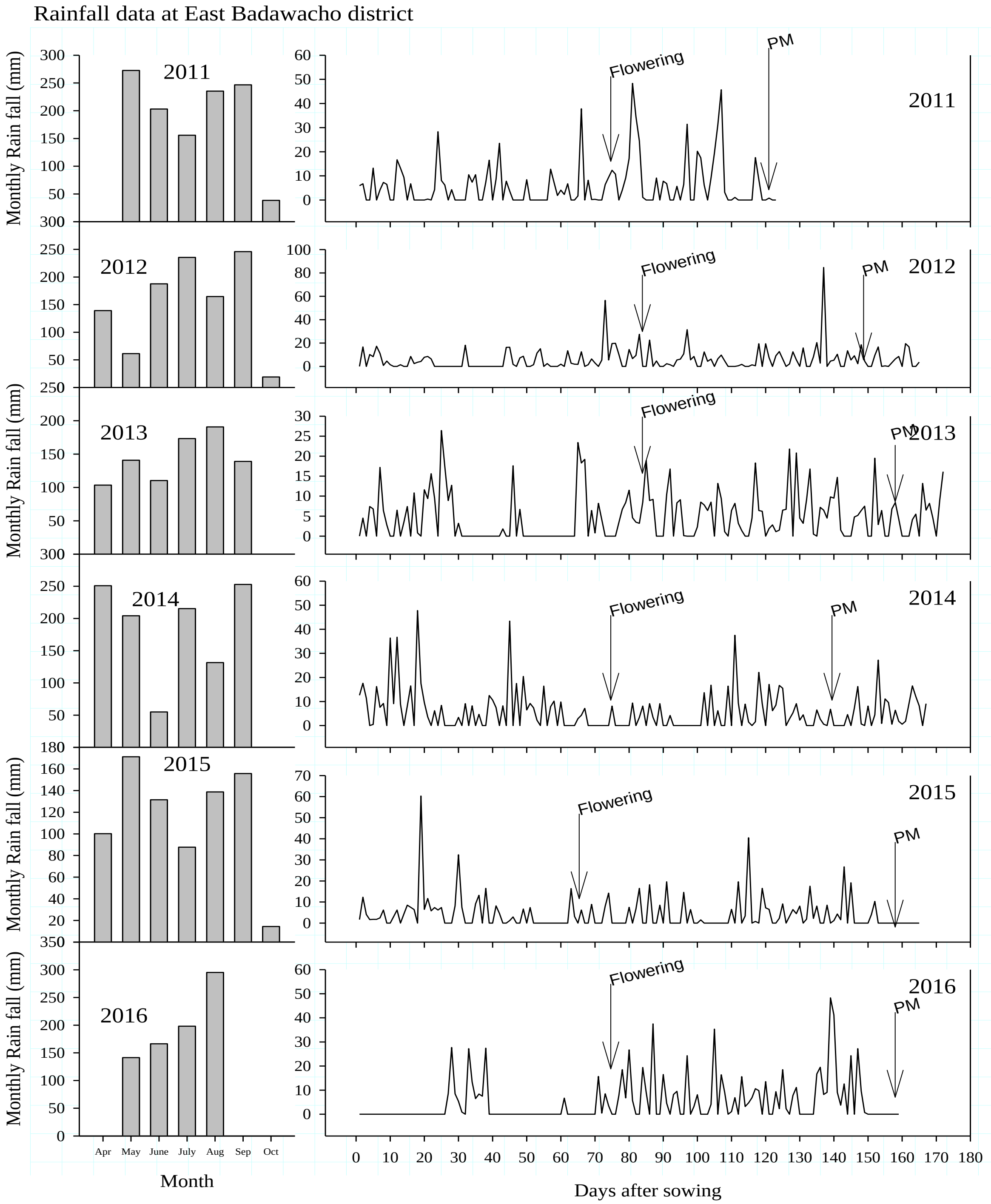

Figure 2. Cumulative monthly rainfall (bar graph) and daily rainfall distribution (line graph) during 2011 - 2016 cropping seasons at East-Badawacho. The arrows indicate flowering and physiological maturity (PM) stages of the crop.

days before planting at the rate of 3-L ha^{-1} to control weed and all plots were maintained weed free afterwards by hand weeding. The conventional farmer practice was hand weeded following the common practice done by farmers. Pest (stem borer) control method (chemical application) used was same for both CA and farmer's practice.

Measurements

Soil water measurement

Composite soil samples from three cores were taken at three depths, 0-15, 15-30 and 30-45 cm, at planting, at bean harvesting

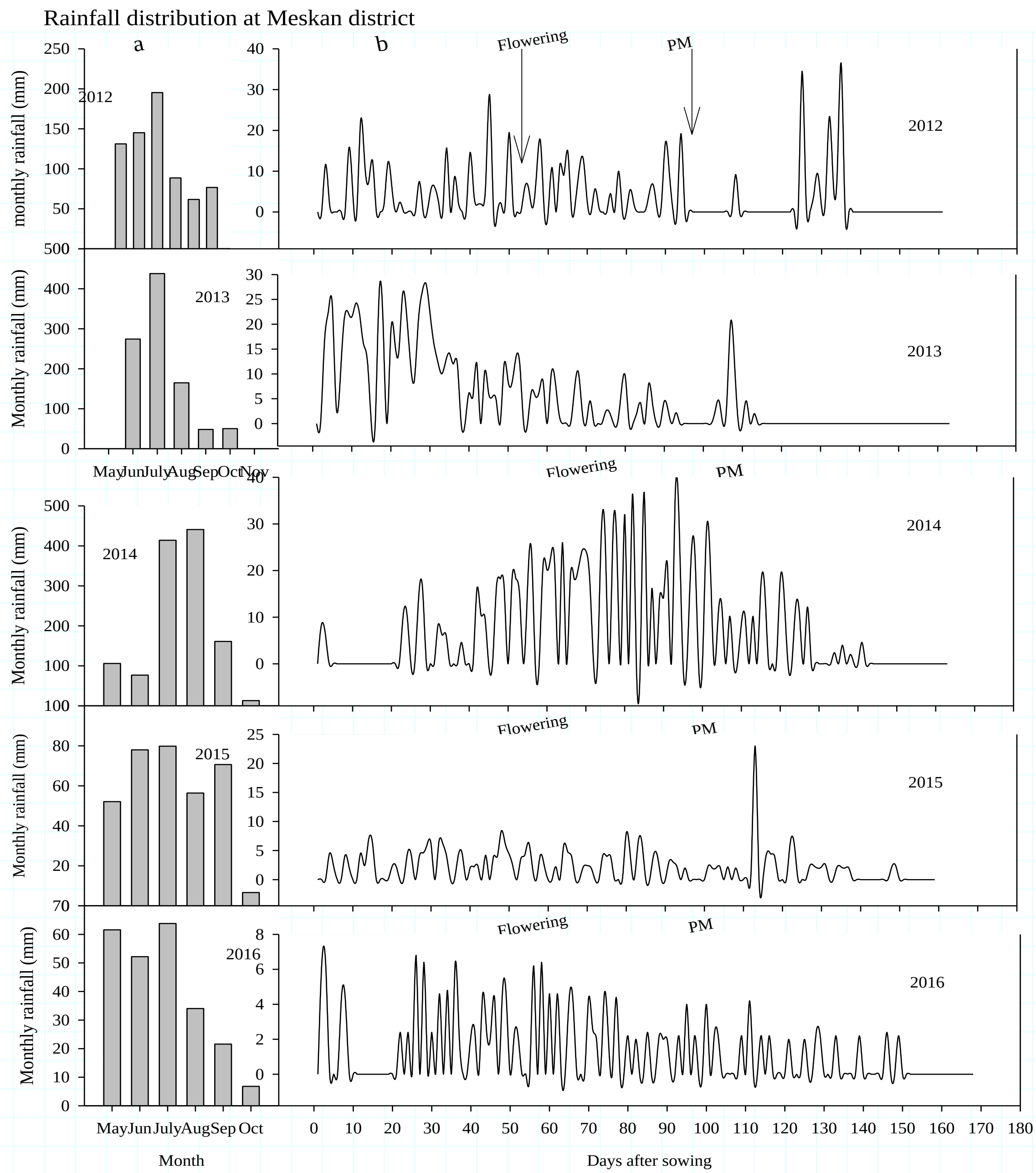

Figure 3. Cumulative monthly rainfall (bar graph) and daily rainfall distribution (line graph) during 2011 and 2016 cropping seasons at Meskan district. The arrows indicate flowering and physiological maturity (PM) stages of the crop.

and maize harvesting every year. The soil samples from each plot were weighed immediately after sampling and oven dried for 48 h at 105°C for final dry weight determination.

NDVI

Normalized Difference Vegetative Index (NDVI) was measured at vegetative and flowering stages at East Badawacho in 2016 using a Green Seeker^{TM} Handheld Optical Sensor Unit (NTech Industries, Inc., USA) (Govaerts et al., 2007; Verhulst et al., 2011).

Biomass yield

Above-ground biomass was measured at physiological maturity of maize from ten sample plant cut at ground level for fresh biomass measurement. From these ten sample plants, a 0.5 kg subsample was taken before oven drying for dry maize biomass weight measurement. For common bean, ten plants were cut at the ground level and dried for biomass. Biomass samples were dried in a fan-circulated oven set at 65°C until constant weight and expressed on dry weight basis (Karim et al., 2000). For common bean, the additional parameters of harvest index (HI), number of

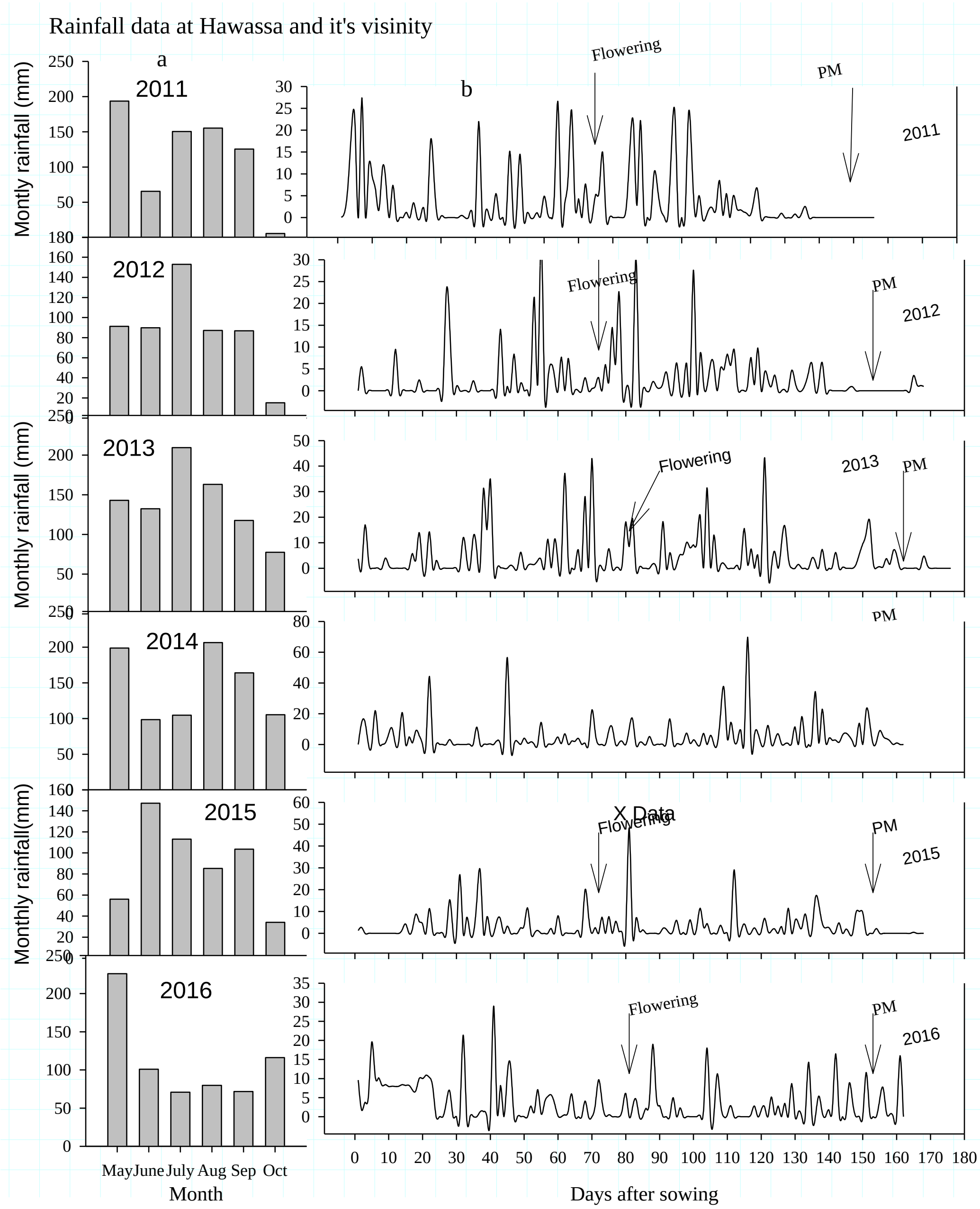

Figure 4. Cumulative monthly rainfall (bar graph) and daily rainfall distribution (line graph) during 2011 to 2016 cropping seasons at Hawassa-Zuriya district. The arrows indicate flowering and physiological maturity (PM) stages of the crop.

pods per plant (PPP), number of seeds per pod (SPP), thousand seed weight (TSW) and plant height (PH) stand count at harvesting time were collected in addition to biomass and grain yield.

Grain yield and yield components for the component crops

Grain yield, pods per plant and number of seeds per pod were assessed for common bean. Plants in the middle 11 rows, from an area of 82.5 m^2 were hand harvested at physiological maturity. Ears were shelled, grain weight and grain moisture content measured, and yield was adjusted for 12.5% grain moisture content. For common bean, total number of pods per plant (PPP) and seeds per pod (SPP) were counted from ten plants and ten pods, respectively. The yield data was then adjusted to 10% moisture content for common.

Statistical analysis

Normality of data was checked prior to analysis of variance (ANOVA) using Shapiro-Wilk normality test. ANOVA for each year

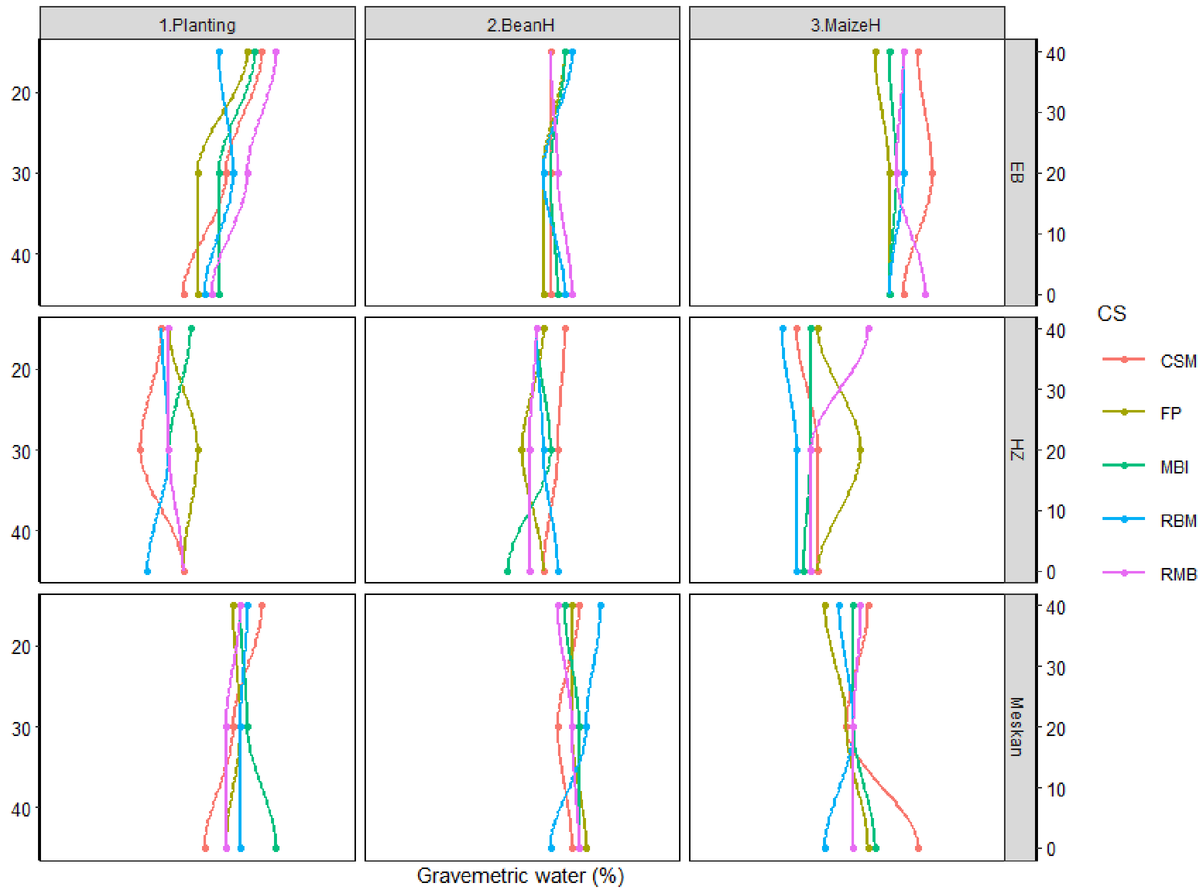

Figure 5. Mean gravimetric soil moisture content (%) for different cropping systems (CS) grown under conservation (CA) and conventional (CN) tillage practices at East-Badawacho (EB), Meskan and Hawassa-Zuriya (HZ) in 2013, 2015 and 2016 cropping seasons. CSM = Continuous sole maize (CA); FP = farmers' practice continuous maize (CN); MBI = maize bean intercropping (CA); RBM = rotation bean maize (CA); RMB = rotation maize bean (CA).

was done for yield and other traits using SAS version 9.0. Analysis was done for each year independently and for all combined years. Means were separated using LSD test. Graphs were developed using sigma plot 10.0 (Systat Software, San Jose, CA).

RESULTS AND DISCUSSION

Soil moisture content

At East-Badawacho, there was significant difference in soil moisture at planting between treatments at 15-30 cm soil depth (Figure 5). The highest soil moisture content was obtained in bean maize rotation treatment. At soil depth of >30 cm the difference in soil moisture was significant at planting time. At maize harvesting, the difference in soil moisture was significant at 0-15 cm soil depth and the highest soil moisture was obtained from CA sole maize (Table 1). At Meskan, a significant difference in soil moisture was detected at bean harvesting at 0-15 cm soil depth. The highest soil moisture was observed in the CA sole maize. At soil depth >30 cm, the difference was significant between treatments at planting, bean harvesting and maize harvesting time. At planting time, at soil depth of >30 cm the highest soil moisture value was obtained from bean maize rotation. At bean harvesting time, the highest soil moisture value was recorded in FP sole maize; whereas at maize harvesting, the highest value obtained from CA sole maize at similar soil depth (Table 1). At Hawassa Zuriya, the difference was significant between treatments >30 cm soil depth, with the highest value obtained from bean maize rotation at planting. At bean harvesting, there was significant soil moisture difference between treatments at soil depth of 0-15 and >30 cm. The highest value was obtained from bean-maize rotation at 0-15 cm soil depth; but at soil depth >30 cm the highest soil moisture was obtained from FP-sole maize.

The result from this study highlighted that the existence of difference for soil moisture holding capacity between tillage practice across cropping systems at different soil depth. Mostly the highest soil moisture at soil depth of above 30 cm under CA highlights that CA practice

Table 1. Average gravimetric soil moisture content (%) at planting, bean harvesting (Bean_H) and maize harvesting (Maize_H) at East-Badawacho, Meskan and Hawassa-Zuriya districts at the three soil depths (0-15, 15-30 and 30-45cm) for different cropping systems in 2013, 2015 and 2016 cropping seasons.

Depth (cm)	Cropping system	East-Badawacho			Meskan			Hawassa-Zuriya		
		Planting	Bean_H	Maize_H	Planting	Bean_H	Maize_H	Planting	Bean_H	Maize_H
0-15	FP	27^{a}	26^{a}	24^{b}	25^{a}	27^{ab}	17^{a}	16^{a}	23^{a}	16^{a}
	RBM	23^{a}	27^{a}	28^{ab}	27^{a}	31^{a}	19^{a}	15^{a}	22^{a}	11^{a}
	MBI	28^{a}	26^{a}	26^{ab}	26^{a}	26^{b}	21^{a}	19^{a}	22^{a}	15^{a}
	RMB	31^{a}	24^{a}	28^{ab}	26^{a}	25^{b}	22^{a}	16^{a}	22^{a}	23^{a}
	CSM	29^{a}	24^{a}	30^{a}	29^{a}	28^{ab}	23^{a}	15^{a}	26^{a}	13^{a}
15-30	FP	20^{b}	23^{a}	26^{a}	26^{a}	27^{a}	20^{a}	20^{a}	20^{b}	22^{a}
	RBM	25^{ab}	23^{a}	28^{a}	26^{a}	29^{a}	21^{a}	16^{ab}	23^{ab}	13^{a}
	MBI	23^{ab}	24^{a}	27^{a}	27^{a}	28^{a}	21^{a}	16^{ab}	24^{ab}	15^{a}
	RMB	27^{a}	25^{a}	27^{a}	24^{a}	27^{a}	21^{a}	16^{ab}	21^{ab}	15^{a}
	CSM	24^{b}	24^{a}	32^{a}	25^{a}	25^{a}	20^{a}	12^{b}	25^{a}	16^{a}
30-45	FP	20^{ab}	23^{a}	26^{a}	24^{ab}	29^{a}	23^{ab}	18^{a}	23^{ab}	16^{a}
	RBM	21^{ab}	26^{a}	26^{a}	26^{ab}	24^{b}	17^{b}	13^{a}	25^{a}	13^{a}
	MBI	23^{a}	25^{a}	26^{a}	31^{a}	28^{ab}	24^{ab}	18^{a}	18^{b}	14^{a}
	RMB	22^{a}	27^{a}	31^{a}	24^{ab}	28^{ab}	21^{ab}	18^{a}	21^{ab}	15^{a}
	CSM	18^{b}	24^{a}	28^{a}	21^{b}	27^{ab}	30^{a}	18^{a}	23^{ab}	16^{a}

Columns with the same letter are not significantly different at $P < 0.05$. FB = Farmers' practice continuous maize (CN); RBM = rotation bean maize (CA); MBI = maize bean intercropping (CA); RMB = rotation maize bean (CA); CSM = continuous sole maize (CA).

contributed more for soil moisture infiltration compared with FP. This more efficient soil water conservation ability of CA than FP provided the chance to harvest higher yield especially under seasons with random drought stress. In line with findings from this study, different investigators reported higher soil moisture under CA compared to FP (Zerihun et al., 2014), higher water infiltration rate more by 15% at low moisture area under CA. But, at potential area (Bako) the infiltration rate of water was less by 16% compared with FP (Liben et al., 2018). Furthermore, in a previous study, higher infiltration rate has been reported from no till practice with four different crop residue conditions (no till with: no input (control), inorganic fertilizer, residues, residue + inorganic fertilizer) compared with conventional practice with four residue conditions mentioned for no till (Kabirigi, 2015). At maize harvesting time, the difference was significant between treatment at soil depth of >30 cm (Table 1). Conservation agriculture is also one way of improving soil moisture management through combining the four principle of conservation agriculture (reducing soil disturbance, maintain permanent soil cover, controlling in field traffic and crop rotation) (Benites and Navarrete, 2003).

NDVI

There was significant difference in NDVI among treatments with the highest observed for rotation and sole maize under CA compared with farmers practice (Table 2). Higher NDVI values for CA than CN at vegetative and flowering reflected higher growth for CA treatments than CN (Table 3) (Verhulst et al., 2011). This was because drought stress conditions enhanced earlier

Table 2. Mean square and mean of NDVI measured at East-Badawacho district for different cropping systems grown under conservation (CA) and conventional (CN) practices in the 2016 cropping season.

Source of variation	DF	Mean Square	Cropping system	NDVI
Farmer	4	0.004	Farmer practice (CN)	0.58[b]
Cropping system	2	0.04**	Sole maize (CA)	0.74[a]
error	8	0.004	Maize rotation (CA)	0.73[a]
CV	-	8.93		
Mean	-	0.68		
LSD	-	-	-	0.09

Table 3. Mean yield (t/ha) and above-ground biomass (t/ha) of maize for different cropping systems (CS) (continuous sole maize (CSM), maize bean intercropping (MBI), rotation maize bean (RMB) and farmers' practice (FP)) grown under conservation (CA) and conventional (CN) tillage practices and % mean performance deviation of each cropping systems against farmers' practice at East-Badawacho, Hawassa-Zuriya and Meskan during 2011 and 2016 cropping seasons.

Parameter		East-Badawacho		Hawassa-Zuriya		Meskan	
		Yield	TDM	Yield	TDM	Yield	TDM
Season	2011	4.4[a]	9.4[b]	6.1[ab]	14.0[a]	3.6[b]	10.8[ab]
	2012	4.2[a]	14.0[a]	3.9[c]	11.4[b]	1.8[c]	10.2[ab]
	2013	4.5[a]	9.8[a]	6.8[a]	9.8[bc]	1.3[c]	6.2[c]
	2014	4.4[a]	16.9[a]	5.1[b]	9.2[bc]	4.4[ab]	12.4[a]
	2015	2.6[b]	9.5[a]	3.2[c]	8.3[c]	4.6[a]	11.3[ab]
	2016	3.6[ab]	10.1[a]	3.5[c]	5.7[d]	4.7[a]	8.3[bc]
CS	CSM	4.0[a]	12.4[ab]	4.7[b]	10.0[ab]	3.6[a]	9.6
	FP	3.8[a]	10.1[b]	5.6[a]	10.9[a]	3.2[a]	10.9
	MBI	3.6[a]	11.5[ab]	4.3[b]	8.8[b]	3.4[a]	10.0
	RMB	4.3[a]	12.9[a]	4.7[ab]	10.0[ab]	3.5[a]	9.9
		Percent mean deviation of cropping systems against farmer practice					
CS	CSM	5.3	22.8	-16.1	-8.3	12.5	-11.9
	FP	-	-	-	-	-	-
	MBI	-5.3	13.9	-23.2	-19.3	6.2	-8.3
	RMB	13.2	27.7	-16.1	-8.3	9.4	-9.2
	CA/FP (%)	4.4	21.5	-18.5	-11.9	9.4	-9.8

Columns with different letters are significantly different at P<0.05.

reduction of the NDVI values (Verhulst et al., 2011). NDVI was significantly affected by tillage conditions, increasing their values from conventional practice to CA on maize in sub-Saharan Africa as also reported previously (Gracia-Romero et al., 2018). The NDVI adequately described the effect of residue mulch on the growth of both rice and wheat crops (Jat et al., 2019), which is also associated with higher grain yield in Western India.

Mean performance of cropping systems for grain yield

At East-Badawacho the data combined across seasons (six years) and cropping systems showed that using a CA practice had higher yield performance than FP by 4% (Table 3). While considering six-year average by each cropping system, RMB and CSM had a higher grain yield advantage over FP by 13 and 5%, respectively. However, maize-bean MBI had inferior yield performance by 5.3% compared with FP considering maize yield only; but inter cropping has bonus yield from common bean, which is an advantage of inter cropping. This confirmed that additional yield of common bean obtained from MBI makes the system more productive compared with the farmer practice and other cropping systems (Table 3). In line with this study's finding, a higher yield advantage was also reported (Yilmaz et al., 2008) from 67% maize mixed with 50% bean or cowpea in both 1 maize:1 bean and 2 maize:2 bean or in one row and two row planting patterns compared to solitary cropping of the same species (Yilmaz et al., 2008).

Under each season, MBI had a 4% advantage compared to FP on maize grain yield during the worst season (2012). The reason may be due to the space between maize rows covered by common bean which helped to protect soil moisture from evaporation and make it available for maize and common bean crops. During the remaining five years (relatively good season compared with 2012 rain fall), the MBI cropping system had inferior performance for maize grain yield compared to FP; without considering the grain yield advantage obtained from common bean. Similarly, there were significantly enhanced yields (7%) under rain fed agriculture from no till in dry climates when the other two CA principles were implemented; but a reverse result was reported, that is a yield reduction by 12% when no till is applied alone (Cameron et al., 2014). RMB had higher grain yield advantage than FP by 25, 15, 5, 26 and 20% in 2012, 2013, 2014, 2015 and 2016, respectively. Only in the first season (2011), RMB under CA had a lower grain yield advantage than FP by 1%. CSM also had higher grain yield advantage than FP by 15, 7, 11 and 16% in 2012, 2013, 2014 and 2015, respectively; but during the starting year (2011) and last year (2016) of the experiment, the performance of CSM under CA had lower performance than FP.

At Hawassa-Zuriya, RMB out yielded FP in 2011 and 2013 by 19 and 2%, respectively. Similarly, higher benefits of crop rotation over continuous sole maize and inter cropping also has been reported (Thierfelder et al., 2012). Result from the six-year and cropping systems combined showed that CA had lower performance compared with farmer practice by 19% (Table 3) which in line with the report of an overall reduction of 6% from no-till (Cameron et al., 2014). When no-till is combined with the other two conservation agriculture principles of residue retention and crop rotation, its negative impacts are minimized and significantly increases rain fed crop productivity in dry climates (Cameron et al., 2014). This suggests that the combination of the three CA components may become an important climate-change adaptation strategy for drier regions of the world.

At Meskan, six-year and cropping systems combined data analysis showed higher performance (9%) was obtained from CA (Table 3). The variation in the performance of cropping systems was due to the seasonal rainfall variability. The combined data analysis at East-Badawacho and Meskan also showed that CA had higher grain yield advantage (7%) than FP. Across seasons, combined data analysis of each cropping systems: CSM, RMB and MBI had higher grain yield compared with FP by 13, 6 and 9%, respectively (Table 3). Considering individual seasons and cropping systems, MBI had higher grain yield advantage than FP in 2011, 2012, 2013 and 2014 by 0.2, 86, 37 and 8%, respectively. RMB also had higher grain yield (109, 68 and 4%) than FP during 2012, 2013 and 2016, respectively. CSM had also superior grain yield (0.2, 71, 59, and 2%) than FP in 2011, 2012, 2013 and 2016, respectively. The higher grain and biomass yield obtained from CA indicated that, under CA maize might have better water use efficiency compared with FP. High water use efficiency has been reported in permanent raised beds with 30% standing crop residue retention compared to treatments ploughed once at sowing with 30% standing crop residue retention and conventional tillage (Araya et al., 2012). Survey results on determinant factors for adoption of crop rotation in Arsi-Negele, Ethiopia, indicated regular education, farming experience (number of years the farmer spent in the agriculture) and frequency of contacts with extension workers in a year had significant contribution for adoption of the practice (Musa, 2014).

Generally, any expansion of CA should be done with caution in drier areas, as implementation of the other two principles (residue retention and crop rotation) is often challenging in resource-poor and vulnerable smallholder farming systems, thereby increasing the likelihood of yield losses rather than gains. A yield benefit with no-till in combination with the other two CA principles in dry climates is probably because of improved water infiltration and greater soil moisture conservation (Serraj and Siddique, 2012). This finding suggests that if no-till applied in combination with the other two conservation agriculture principles, CA can become an increasingly important strategy to deal with soil moisture stress due to climate change. It is precisely resource-poor and vulnerable smallholder farming systems that will have the greatest challenges adopting the other two principles, most notably the retention of crop residues due to strong competition for residues by livestock and other uses (Erenstein et al., 2012; Giller et al., 2009). The comparative productivity analysis between continuous maize, maize intercropped with cowpea or pigeonpea and maize in rotation with cowpea or sunnhemp, showed marked benefits of rotation especially in CA systems (Thierfelder et al., 2012). Higher maize grain yield under CA practices has been reported compared with the maize grain yield from conventional practice (Kabirigi, 2015).

In combined data analysis across framers' fields for each year, the highest grain yield was at East Badawacho (4.5 t ha^{-1}) and Hawassa-Zuriya (6.8 t ha^{-1}) districts in 2013 cropping season. At Meskan, the highest yield was recorded in 2016. For data combined across season at each district, the highest grain yield obtained from RMB, FP and CSM at East Badawacho, Hawassa-Zuriya and Meskan, respectively, compared with the other cropping systems. CSM was the second-highest yielder cropping system at the three districts. RMB was also high yielder at Hawassa-Zuriya. At East-Badawacho, RMB and CSM had higher grain yield over FP with values of 13.2 and 5.3%, respectively. At Meskan, CSM, RMB

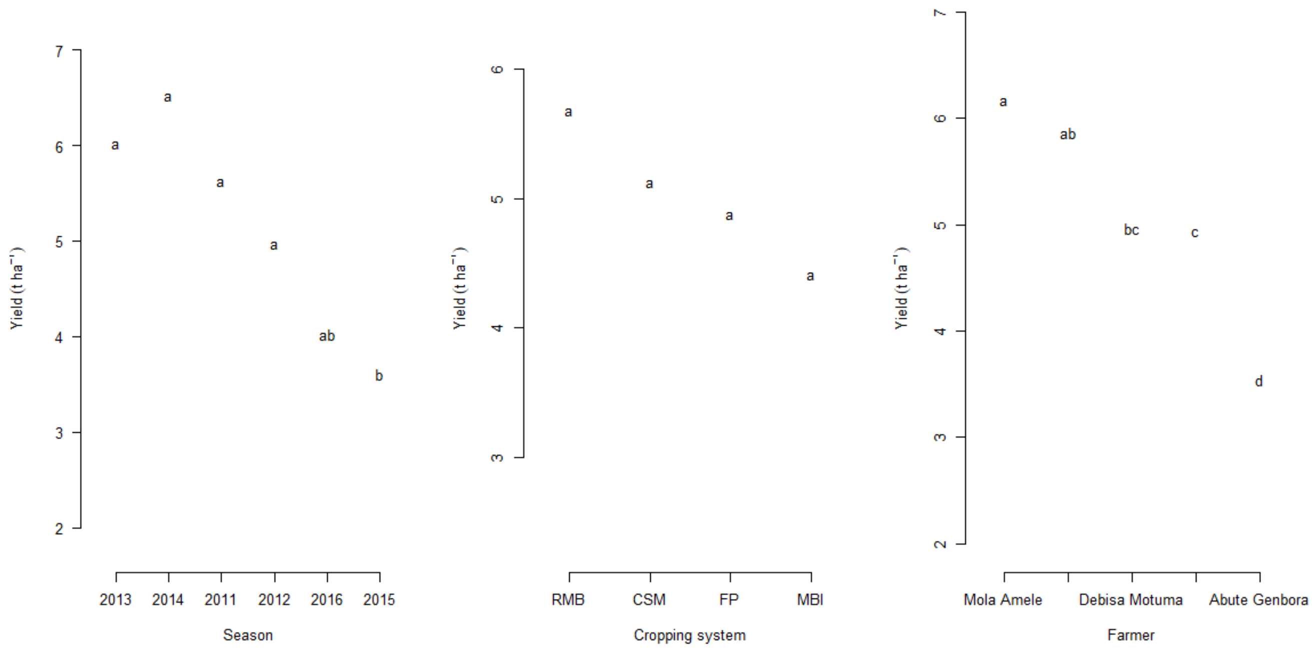

Figure 6. Maize yield variation among seasons, cropping systems and farmers used for the study during 2011 to 2016 cropping seasons at East-Badawacho district in Ethiopia. FP, RMB, CSM and MBI are farmers' practice, Rotation maize bean, continuous maize and maize bean intercropping, respectively. 2011 to 2016 are seasons. The bars indicate interquartile yield range for the seasons, cropping systems and farmers used for the study and bars with the same letter are not significantly different at $P < 0.05$.

and MBI under CA had higher grain yield than FP. Under combined data analysis across location and season the highest grain yield was obtained from RMB, FP and CSM in East-Badawacho, Hawassa-Zuriya and Meskan districts (Figures 6 to 8). For combined data across seasons and cropping systems, CA had higher mean grain yield performance than FP at East-Badawacho and Meskan with the magnitude of 4.4 and 9.4%, respectively. The GGE-biplot graphical analysis showed that BAMR3 and SM3 cropping practice under CA were more suitable for East-Badawacho but for Meskan and Hawassa-Zuriya, the three practices (BAMR1, SM1 and FP1) were good performing practices but the other seven combinations were not represented for three testing locations (Figure 9).

Mean performance of cropping systems for biomass yield

In the across season and cropping systems analysis for biomass yield, the mean performance of cropping systems under CA was 22% compared with FP at East-Badawacho (Table 3). In across season combined data analysis, MBI, CSM and RMB exhibited higher biomass yield than FP by 14, 28, and 23%, respectively. During each season, MBI had higher performance than FP in 2012, 2014, 2015 and 2016 with magnitude of 4, 30, 24, and 52%, respectively. RMB had higher biomass yield than FP; with the value of 14, 17, 31, 77 and 42% in 2012, 2013, 2014, 2015 and 2016, respectively, except in 2011 (first experimental season). CSM had higher biomass yield (4, 3, 29, 30, 64, 17%) than FP in 2011, 2012, 2013, 2014, 2015 and 2016, respectively. Generally, the higher maize grain and biomass yield in 2016 evidence is supported by availability of high chlorophyll content in maize leaf at vegetative and flowering stage of the crop compared with FP (Table 2).

At Hawassa-Zuriya, MBI had higher biomass yield than FP in 2011 and 2016 by 11 and 2%, respectively. RMB exhibited higher biomass yield in 2011, 2013 and 2016 with the magnitude of 42, 2 and 7%, respectively. CSM also had higher biomass yield with the value of 53% in 2011 cropping season, this treatment had also inferior performance compared with FP during the other cropping seasons. Previously, significantly higher stover yield from CA practices compared with the conventional practices (Kabirigi, 2015).

At Meskan, the combined data across seasons and cropping systems showed that CA had inferior performance by 10% compared with FP. While considering each cropping systems at each season, MBI had higher biomass yield than FP in 2011, 2013 and 2016 with the magnitude of 20, 53, and 56%, respectively. RMB also had higher biomass yield than FP in 2011, 2013 and 2016 with value of 21, 41, and 26%,

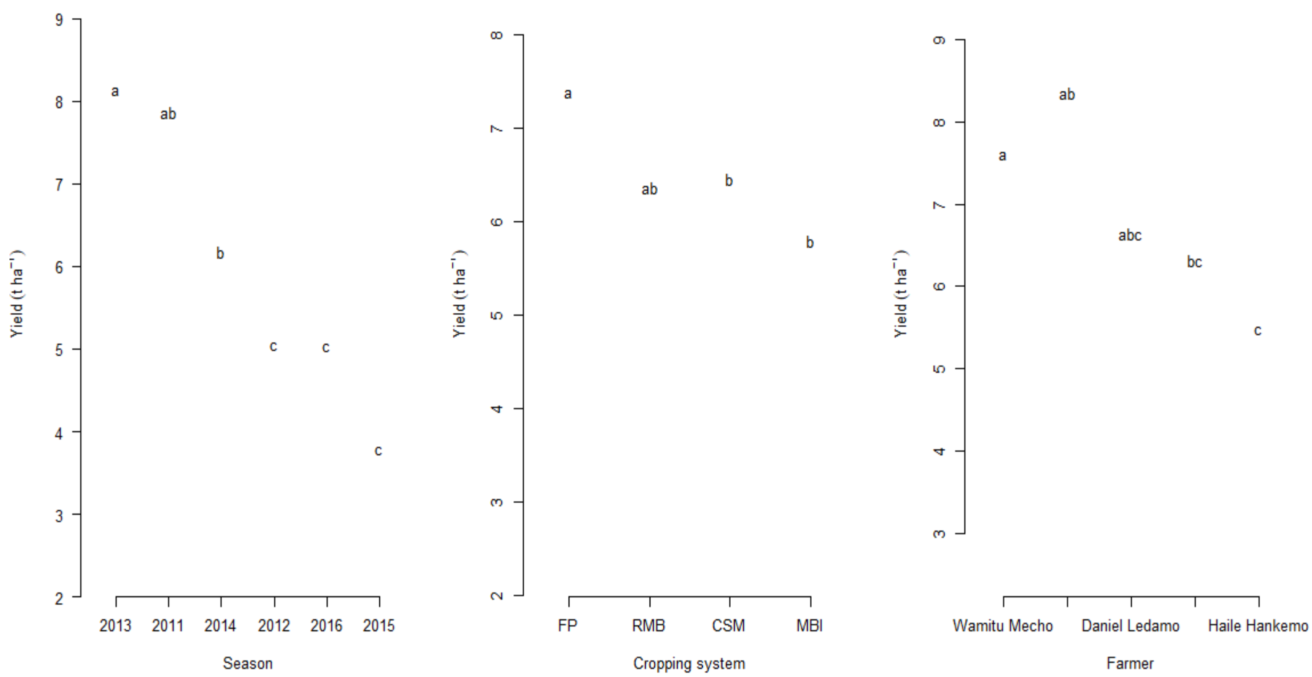

Figure 7. Maize yield variation among seasons, cropping systems and farmers used for the study during 2011 to 2016 cropping seasons at Hawassa-Zuriya district in Ethiopia. FP, RMB, CSM and MBI are farmers' practice, Rotation maize bean, continuous maize and maize bean intercropping, respectively. 2011 to 2016 are seasons. The bars indicate interquartile yield range for the seasons, cropping systems and farmers used for the study and bars with the same letter are not significantly different at $P < 0.05$.

respectively. Similarly, CSM had higher biomass yield than FP in 2011, 2013 and 2016 with magnitude of 11, 55, and 83%, respectively.

In across season and location combined data analysis for TDM, RMB and CSM had higher biomass advantage over FP by 7 and 2%, respectively; but the performance of MBI was lower by 22%. For each cropping system in each season combined across locations, MBI showed TBM yield in 2011 and 2016 with magnitude of 6 and 36% compared to FP, respectively. However, during the remaining seasons, this treatment had inferior performance than FP. RMB also had relatively higher biomass advantage than FP in 2011, 2013, 2015 and 2016; with magnitude of 22, 14, 14, and 25% respectively. CSM had better performance over FP in 2011, 2013, 2015 and 2016 with magnitude of 28, 20, 14, and 22%, respectively. The overall TDM performance of CA was higher by 7% compared with FP based on the average data from across six-year locations analysis.

For the data combined across cropping systems under each location, the highest TDM value was obtained in 2014, 2011 and 2015 at East-Badawacho, Hawassa-Zuria, and Meskan, respectively with values of 16.9, 14.0 and 11.3 t ha^{-1}, respectively. All cropping systems under CA had higher TDM at East-Badawacho and Meskan over FP; whereas at Hawassa-Zuria, FP had higher performance for grain yield and TDM compared with the other cropping system under CA (Table 3). At East-Badawacho, CA showed higher performance (21.5%) compared with FP for TDM. However, at Hawassa-Zuriya and Meskan districts, the overall performance of CA was lower than FP for TDM (Table 3). Similar to the higher TDM under CA than FP found at East-Badawacho in this study, higher biomass production from maize rotation compared to continuous sole maize has been reported for research conducted for long term CA trials in Zimbabwe under CA (Thierfelder et al., 2012). In this study, the increase in grain and biomass yield under no tillage is in contrast with the inferior performance of CA with zero tillage and wheat straw mulch compared with conventional practice (Mehmood et al., 2014).

Common bean performance

Regarding the common bean performance, for bean rotation the mean was 2978 kg ha^{-1} for grain yield and for inter cropping the mean value was 935 kg ha^{-1}across seasons and locations. The grain yield and biomass production from inter cropping is the additional gain in produce on maize yield for farmer. The combined mean data across location and season also showed that, the biomass yield of bean from bean rotation and inter cropping were 5045 and 1658 kg ha^{-1}, respectively (Table

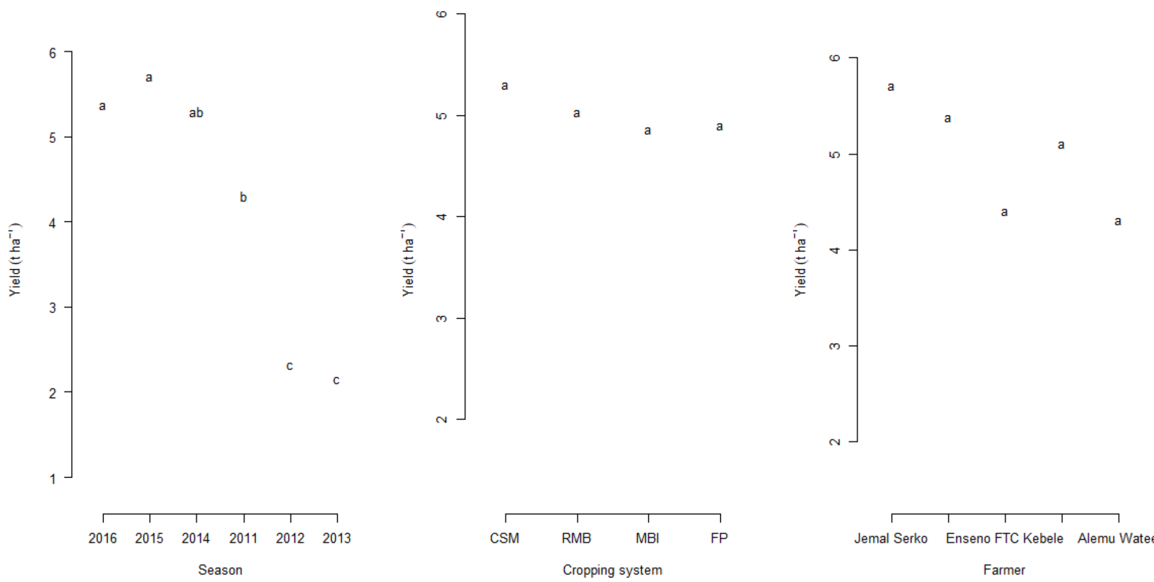

Figure 8. Maize yield variation among seasons, cropping systems and farmers used for the study during 2011 to 2016 cropping seasons at Meskan district in Ethiopia. FP, RMB, CSM and MBI are farmers' practice, Rotation maize bean, continuous maize and maize bean intercropping, respectively. 2011 to 2016 are seasons. The bars indicate interquartile yield range for the seasons, cropping systems and farmers used for the study and bars with the same letter are not significantly different at $P < 0.05$.

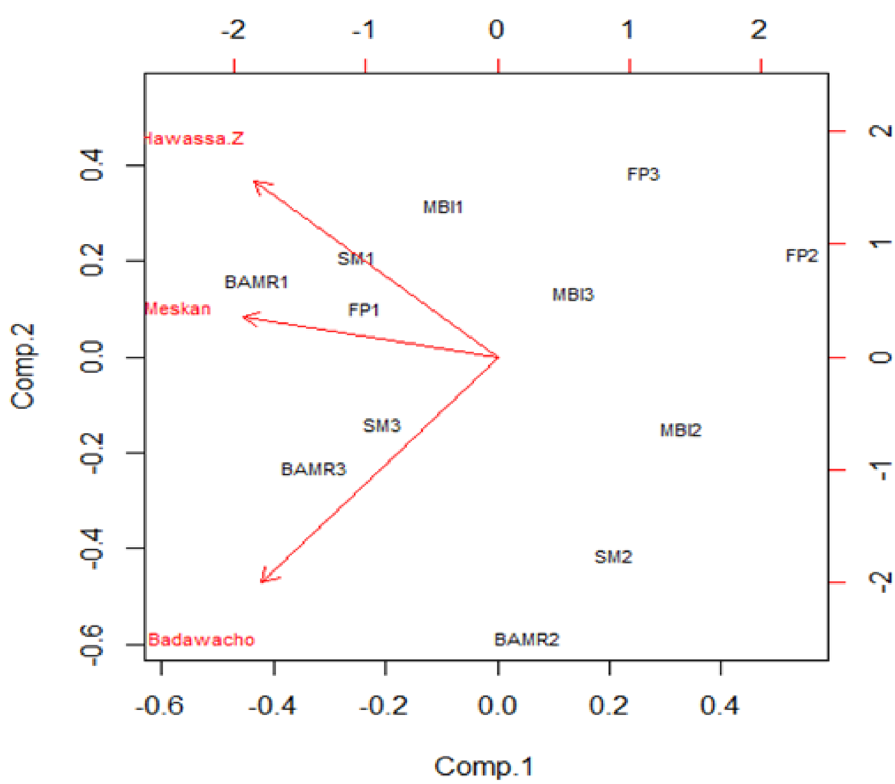

Figure 9. The "discrimination and representativeness" view of GGE biplot for maize yield from four cropping systems (sole maize (SM), maize after bean rotation (BAMR), maize bean intercropping (MBI) and farmers' practice (FP)) grown under conservation (CA) and conventional practices (CN) at East-Badawacho, Hawassa-Zuriya and Meskan during 2011 - 2016 cropping seasons.

Table 4. Mean performance of common bean combined data across (season and location) 2011-2016 under CA.

Treatment	TDM (t/ha)	GY (t/ha)	HI (%)	PPP (#)	SPP (#)	TSW (gm)	SHAV #/ha	NP/m^2 (#)	PH (cm)
Bean rotation (CA)	5.1^a	3.0^a	59.0^a	19.0^a	6.0^a	257.0^a	1648.0^a	17.0^a	50.0a
Inter cropping (CA)	2.0^b	1.0^b	56^a	13.0^b	5.0^b	254.0^a	788.0^b	8.0^b	44.6b
CV (%)	34.2	32.2	30.5	35.4	12.7	17.5	21.4	21.4	20.3
F-test	***	***	ns	***	***	ns	***	***	***

TDM= Total dry matter, GY= grain yield, HI= harvest index in %, PPP= pod per plant (#), SPP= seed per pod (#), SHAV= stand count at harvest (#), NP/m^2= number of plants per meter square (#), PH= plant height (cm).

4). Bean rotation had higher performance than inter cropping under CA practice for HI, PPP, TSW and PH (Table 4).

Conclusion

The overall assessment of cropping systems under CA and FP indicated that, cropping systems under CA performed better than the farmer practice both under normal and poor-quality seasonal rainfall conditions. Soil moisture content from CA practices was higher than that of famer practices. Under rainfall shortage conditions, the crop yields from cropping systems under CA were higher compared with the farmer practice for grain yield and biomass due to CA practices conserving soil moisture. During the presence of rainfall shortage, maize-bean inter cropping had relatively higher potential compared with the other cropping systems under CA and farmer practice. Considering production from maize crop only, maze rotation had relatively higher maize grain yield and biomass potential compared with others. Considering the merit in reduction rainfall risks and having addition yield from common bean, maize-bean inter cropping is better.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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