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Identification of best maize-legume based cropping systems under conservation agriculture practices for Central Rift Valley of Ethiopia

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Cereal crops especially maize production in Ethiopian Central Rift Valley is affected by biotic and abiotic production. This study was conducted for two seasons (2015-2016) and the best cropping system was identified using Randomized Complete Block Design with three replications. The experiment had six treatments (1) Continuous mono-cropping under conventional practice (CN), (2) continuous mono cropping under conservation agriculture (CA) (3) relay cropping (CA) with double bean planting within a season (maize bean inter-cropping: second round bean planting was conducted after immediate harvesting of the first bean), (4) Double cropping (CA) (maize bean inter cropping after sole lablab), (5) Double cropping (CA) (maize after bean) and (6) Double cropping (CA) (bean after maize). In 2016, the highest maize biomass yield and maximum water use efficiency were obtained from double cropping bean after maize with value of 16050 kg/ha and 31 kg mm^{-1}, respectively. Maize-bean relay cropping outperformed the sole maize under CA and CN by 182 and 138% for maize grain yield. Water use efficiency of double cropping (maize after bean) and relay cropping was higher than double cropping (bean after maize) by 366 and 197% in 2015 for maize grain yield. For biomass, relay cropping under CA and sole maize under CN had similar water use efficiency of 18 kg mm-^{1}. The CA practice with diverse crops planted together: double inter-cropping at different time (relay cropping) and double cropping under CA are good options for using the residual soil moisture and to sustainably improve crop productivity.

Key words: Conservation; cropping system; lablab; water use efficiency.

INTRODUCTION

The major concerns for food security and agricultural development in Africa include soil fertility, management of water resources, access to improved crop varieties and livestock breeds as well as improving extension services

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(Love et al., 2006). Climate variability is a major source of risk in crop production since it affects crop growth and development, which results in yield reduction. In the semi-arid environments of Ethiopia, the challenges addressing climate risk are attributed to the large uncertainties of the climate variability (Conway and Schipper, 2011; Tesfaye et al., 2016). The amount and temporal distribution of rainfall is generally the most important determinant of interannual fluctuations in national crop production levels in Ethiopia (Demeke et al., 2004). A close relationship between rainfall and maize yield has been reported for the sub-Saharan Africa region (Cairns et al., 2013; Seyoum et al., 2017).

Soil moisture is the most limiting factor for crop production in the semi-arid regions. Hence, the pattern and amount of rainfall are among the most important factors that affect agricultural systems (Osman and Sauerborn, 2002). It governs the crop yields and determines the choice of the crops that can be grown (Tesfaye and Walker, 2004). This is because, the length of the growing period for a crop in an environment depends on the duration of the rainy season (onset and cessation), temperature and soil water holding capacity and nutrition (Seyoum et al., 2017; Tesfaye and Walker, 2004). The risk of water stress during critical growth stages (flowering and grain filling) can be minimized by matching the resource available following sowing opportunity with suitable cultivars and crops (Tesfaye and Walker, 2004).

Crop diversification in space and time under various managements has been offering great opportunities for smallholder farmers in increasing productivity and stabilizing crop yields in variable climates of semi-arid regions (Bezabih and Sarr, 2012; Rurinda et al., 2014). Cereal legumes combination has been at the center-stages of such approaches (Kamanga et al., 2009; Shiferaw et al., 2014). Farmers in southern Ethiopia are also known for using the most diversified cropping systems with legumes and other root crops for higher land use efficiency (Alene et al., 2006). Under conditions where the component crops selected by farmer complement each other, the roots of each crop occupy different soil horizons, reducing considerably the potential competition between species and improve total soil nutrient uptake from the soil at different soil depth by the component crops (Gliessman et al., 1980). The deep-rooted species have the potential to use soil nutrients and other soil resources which is beyond the reach of roots of grass or other annual crops (Chikowo et al., 2006). However, the component crops productivity and efficiency should be improved by using the best combination of management practices and technologies for sustainable productivity and increased resilience. In water-limited semi-arid environments, conservation agriculture (CA) has been acknowledged for *in-situ* water conservation effect (McHugh et al., 2007) and soil health improvements (Rockström et al., 2009). This is because CA practices can help mitigate intra-seasonal water stress through its *in-situ* water conservation.

Land scarcity is one of the constraints facing small farmers in Ethiopia. In the Southern Ethiopia, 40% of farmers have an average land holding of 0.1 to 0.5 ha with a further 30% having 0.51 to 1 ha (CSA, 2017). This led farmers to use multiple cropping to increase yield per unit area and reduce the risk from crop failure due to climate change. 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)' it 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). Therefore, the objective of this study is to identify the best cropping system and agricultural practices that help improve land and water productivity of maize-based cropping systems in the Central Rift Valley of Ethiopia.

MATERIALS AND METHODS

The study sites

The experiment was conducted at Hawassa Research Station (38°30ˈ88 " E, 07°03ˈ71 " N, and 1689 masl) in Ethiopia. This experiment was conducted for two years during the 2015 and 2016 main cropping seasons (summer season) under rain-fed conditions. This location is characterized by a long season (extended from March to September) and bimodal rainfall distribution. The cumulative annual rainfall in 2015 and 2016 cropping seasons was 671 and 985 mm, respectively. The location is characterized by mean highest and lowest temperature of 27.3 and 12.6°C, respectively. The soil type at Hawassa is vitric Andosols with 80-152 cm depth and slope ranging from 0 to 2% (Abaineh et al., 2006) and slightly acidic to neutral; the topsoil (0-30 cm) pH values are between 6.4 and 6.9. The cropping system in the Hawassa smallholder farming area is largely continuous sole maize (*Zea mays* L.) under conventional oxen ploughing practice.

Description of treatments and experimental set up

Six treatments comprising five cropping systems under conservation agriculture and one conventional practice were evaluated using a randomized complete block design (RCBD) in three replications. The six treatments tested during the experimentation are described as follows;

1. Treatment 1: Continuous maize mono-cropping under conventional practice (CN)
2. Treatment 2: Continuous maize mono cropping under conservation agriculture (CA)
3. Treatment 3: Relay cropping with double bean inter -cropping at different time within a season under conservation agriculture (CA)
4. Treatment 4: Double cropping (bean after maize within a season) under conservation agriculture (CA)
5. Treatment 5: Double cropping (maize after bean within a season) under conservation agriculture (CA)
6. Treatment 6: Double cropping (maize-bean inter cropping after sole lablab) under conservation agriculture (CA)

For CA treatments, planting rows were opened using a hand-hoe to the required depth of about 10 cm to place seeds and for basal fertilizer application without any soil disturbance before planting of the component crops. For conventional tillage practice (CN), the traditional farmers' land preparation for maize and common beans at Hawassa was used. The traditional practice is characterized by, repeated ploughing using ox, removal of crop residue from the field, burning of crop residue and other common practices, meaning that this practice is cultivated similar to the traditional land preparation practice of farmers planting maize and common beans (*Phaseulus vulgaris* L.) at Hawassa. Land was ploughed with an ox-drawn traditional plough called Maresha 2 to 3 times before planting. Each plot had six rows of 3.6 m length. Maize was planted at a spacing of 75 cm between rows and 30 cm between plants while common bean (*Phaseolus vulgaris* L.) was planted at 40 cm between rows and 10 cm between plants. Two seeds were planted per hill, and later thinned to one seedling per hill 15 days after emergence to maintain a desired plant density of 44444 plants ha^{-1} for maize and 250,000 plants ha^{-1} for common bean.

Experimental management

The recommended fertilizer rates at Hawassa 110 kg N and 46 kg P_2O_5 ha^{-1} were applied to all maize treatments. All phosphorous and 1/3 of the N fertilizer was applied at planting while the remaining 2/3 of N was side-dressed between 25 and 35 days after maize emergence (Ritchie et al., 1989). The source of phosphorous and N was P_2O_5 and urea, respectively. For common bean, 46 kg P_2O_5 and 37 kg N ha^{-1} were applied at planting. The released maize (MH-130 with 130 days for maturity) and common bean (Hawassa-Dume with 102 maturity days) varieties were used in the experiment. Common bean was planted at the same time with maize and bean was intercropped between maize rows. A broad-spectrum systemic herbicide (glyphosate) was sprayed for CA treatments seven days before planting at 3-liters ha^{-1} and all plots were kept weed free afterwards by using manual hoe method whenever necessary. All maize crop residues and/or common bean biomass retained in the field from the previous cropping season were used as mulch in CA treatments. All crop residues were cut and carried for feed and fuel immediate after harvest from CN treatments, similar to the farmers' practice at Hawassa. During second planting the maize crop was highly affected by different biotic and abiotic stresses especially due to maize lethal necrosis disease. As a result of these production constraints, biomass yield was computed only for data collected from first round planting (Table 3).

Agronomic measurements and statistical analysis

Above-ground biomass, grain yield, stand count at harvest and phenological data such as days to anthesis, silking and maturity were recorded for maize, while grain and biomass yields, number of pods per plant (PPP), number of seeds per pod (SPP), thousand seed weight (TSW) and harvest index (HI) were recorded for common bean. The rainfall water use efficiency, that is, kg of grain and biomass per mm rainfall, was calculated. Ten maize and common bean plants were cut just above ground level for biomass sampling per replication for each treatment. From ten sampled maize plant, 0.5 kg sub sample and the whole ten common bean plants were dried for 72 h at 70°C for dry weight measurement (Karim et al., 2000) until constant dry weight. The grain yield of maize and common bean was adjusted to 12.5 and 10% grain moisture content, respectively. The data were analyzed using SAS version 9.0 (SAS, 2002) for each trait. The analysis was done for each season and then combined over seasons. Before water use efficiency computation, grain yield of common bean was converted into maize grain yield considering the amount of Ethiopian birr generated from bean and how much maize grain yield can be purchased. Finally, the maize grain yield harvested from the plot directly and obtained from the bean yield conversion was added for the treatment which had both maize and bean crops.

$$\text{WUE} = \frac{\text{Grain yield produced}}{\text{Rain fall from planting to maturity}} \quad (1)$$

Production efficiency

Production efficiency of crop management practices consists of mixture of cropping systems, and was evaluated using equivalent yield (EY) and relative production (RP) efficiency (Samant, 2015). The relative comparison between the existing cropping system (conventional practice) and CA practices was done by the recent approaches vis-a-vis relative production efficiency (RP %) and equivalent yield (EY). The average yield of component crops was converted into maize equivalent yield (MEY) based on the price using the method suggested by Sankaranarayanan and Praharaj (2012) and Samant (2015) to compute RP.

$$\text{MEY (kg/ ha)} = \text{Y (kg/ha)} \left(\frac{\text{P (ETB/ kg)}}{\text{PM (ETB/kg)}}\right) \quad (2)$$

Where, MEY is maize equivalent yield; Y is the yield of common bean (kg/ha), P (12 kg^{-1}) and PM (5 kg^{-1}) are the average price of the legume crops and maize, respectively in Ethiopian Birr per kg (ETB kg^{-1}) during their production years, kg/ha is the grain yield harvested per 10000 m^2 of farm land.

For calculating the equivalent yield in terms of crop equivalent grain yield, maize yield and maize equivalent yield of legume crops were summed up and expressed as t ha^{-1}. Thus, the RP% of the system was computed using the method followed by Sankaranarayanan and Praharaj (2012) (Equation 3):

$$\text{RP \%} = \left(\frac{\text{EYD} - \text{EYE}}{\text{EYE}}\right) * 100$$

Where, RP is relative production efficiency; EYD is the crop equivalent yield under improved system and EYE is the equivalent yield under existing cropping system (conventional practice).

RESULTS AND DISCUSSION

Performance of different cropping systems

During the two main growing seasons (summer), the experimental site received total rainfall amount of 671 and 985 mm in 2015 and 2016, respectively. Rainfall totals for some of the years are summarized in Figure 1. The cropping systems effects on grain and dry biomass yields, harvest index, plant and ear heights were not significantly different in 2015 (Table 1). In 2016, the treatments had significant effects on grain and biomass yields, plant and ear heights. Across the seasons, the difference between treatments was significant for grain and biomass yields, and HI (Table 1). Similarly, Daniel (2019) reported significant difference between cropping systems (sole, relay copping of maize with different common bean and other forage crops) for biomass and grain yield and harvest index. Seasons had significant effects on the measured parameters. The season

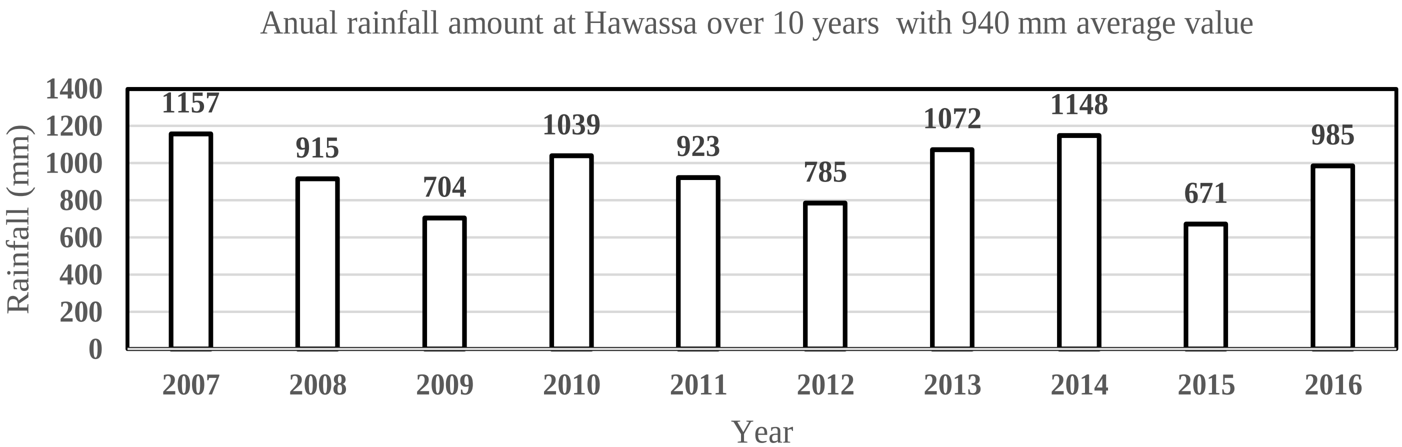

Figure 1. Cumulative annual rainfall (mm) during the period between 2007 and 2016 at Hawassa. The average annual rainfall for the last 10 years was 940 mm.

Table 1. Mean grain yield (GY) (kg/ha), biomass (BY) (kg/ha), plant height (PH) (cm), ear height (EH) (cm) harvest index of maize for different cropping systems grown in the 2015 and 2016 cropping seasons at Hawassa.

Cropping system	GY	BY	PH	EH	HI (%)
2015					
Sole maize (CN)	1453[a]	7409[a]	156[a]	79[a]	0.22[a]
Sole maize (CA)	1444[a]	6854[a]	153[a]	72[a]	0.24[a]
Double cropping (bean after maize) CA	1337[ab]	7118[a]	159[a]	80[a]	0.21[a]
Relay (maize + bean) + (bean) under CA	972[b]	5980[a]	148[a]	71[a]	0.18[a]
CV (%)	16.4	26.1	8.1	7.4	18.7
F-test	ns	ns	ns	ns	Ns
2016					
Sole maize (CN)	4215[a]	9324[b]	169[a]	78[a]	0.52[a]
Sole maize (CA)	3557[a]	8363[b]	153[a]	78[a]	0.47[ab]
Double cropping (bean after maize) CA	3677[a]	16050[a]	128[b]	52[b]	0.27[b]
Relay (maize + bean) + (bean) under CA	2626[b]	5568[b]	152[a]	65[ab]	0.54[a]
CV (%)	12.2	30.0	7.4	12.1	26.0
F-test	*	*	*	*	Ns
Combined over seasons					
Sole maize (CN)	2834[a]	8366[b]	162a	78[a]	0.37[a]
Sole maize (CA)	2500[a]	7608[b]	153ab	75[ab]	0.35[a]
Double cropping (bean after maize) CA	2507[a]	11584[a]	144[b]	66[b]	0.24[b]
Relay (maize + bean) + (bean) under CA	1799[b]	5774[b]	150[ab]	68[ab]	0.36[a]
CV (%)	16.4	28.8	8.2	11.4	25.2
Cropping system (CS)	**	**	ns	ns	*
Season (S)	***	**	ns	*	***
CS * S	ns	*	*	*	*

treatment interaction had significant effects on biomass yield and HI, indicating the cropping systems had inconsistent performance across the seasons. The cropping system season interaction had no significant influence for grain yield indicating that, the cropping systems effects were similar during the two seasons. In 2016, superior maize grain yield was recorded from conventional practice, followed by double cropping (bean after maize). Similar performance was observed from these treatments across the seasons. In 2016, the

Table 2. Mean grain yield (GY) (kg/ha), biomass (BY) (kg/ha), pods per plant (PPP), seeds per pod (SPP), thousand seed weight (TSW) (g) and harvest index (HI) of common bean for different cropping systems grown in the 2015 and 2016 cropping seasons at Hawassa.

Testing year and planting round	Treatments	GY	Biomass	PPP	SPP	TSW	HI
First round planting in 2015	Double Cropping (maize after bean) under CA	2618[a]	4427	25	6	240	0.45
	Relay (maize + bean) + (bean) under CA	1263[b]	1507	21	5	234	0.58
	CV (%)	5.7	32.5	12.9	5.9	4.5	30.0
	F-test	**	ns	ns	ns	ns	Ns
First round planting in 2016	Double Cropping (maize after bean) under CA	3149[a]	4899[a]	19[a]	5	320	0.54
	Relay (maize + bean) + (bean) under CA	1729[b]	4466[a]	20[a]	5	230	0.31
	Lablab then (maize + bean) under CA	-	5410[a]	9[b]	-	-	-
	CV (%)	14.8	10.2	14.6	5.9	27.1	23.3
	F-test	*	ns	***	ns	ns	Ns
Second round planting in 2016	Double Cropping (bean after maize) CA	2107[a]	4338	15	5	262	0.48
	Relay (maize + bean) + (bean) under CA	1353[b]	3237	20	5	244	0.39
	Lablab then (maize + bean) under CA	2038[a]	4004	16	5	267	45
	CV (%)	12.6	30.5	26.2	6.0	4.4	21.4
	F-test	*	ns	ns	ns	ns	Ns

highest above ground biomass yield (16050 kg/ha) was observed from double cropping (bean after maize), followed by conventional practice which had 9324 kg/ha. In contrast to this study Daniel (2019) reported the higher biomass from relay cropping as compared to results from inter and sole cropping; however, the author did not compare with double cropping (bean after maize). Across the years, double cropping (maize after bean) and sole maize under conventional practice had high biomass yield of 11584 and 8366 kg/ha, respectively which is relatively higher as compared with the remaining four cropping systems in this experiment (Table 1). The higher bean grain and biomass yields were obtained from double cropping (maize after bean) and relay cropping in 2016 compared with results from 2015 based on first round planting. Bean grain yield from double cropping (maize after bean) was higher by 20% in 2016 than 2015. Bean grain yield produced in 2016 from relay cropping was 37% higher than grain yield obtained in 2015 from first round planting (Table 2).

While considering the productivity of the cropping systems from the first and second round planting in 2016, the highest bean grain yield was harvested from double cropping (bean then maize) with the average value of 3149 kg/ha but the maize crop was not successful at second round planting. In contrast, relay cropping (maize + bean) + bean) which had additional maize yield (2626 kg/ha) from first planting also had 1729 kg/ha of bean from the first round and 1353 kg/ha from second round planting (Table 3). Similarly, the cowpea crop in cowpea-maize relay cropping is found to be profitable for all fertility levels and is selected as good option from cropping systems in Ghana (Marinus, 2014). Regarding double cropping, planting maize at first round followed by common bean during the second planting had remarkable potential in exploiting available residual soil moisture because this cropping system provided reasonable grain yield by both component crops (maize and common bean crop) compared with the reverse cropping system (bean then maize). Sandler and Nelson (2016) also reported higher yields for radish crop from relay-intercrop and double-crop system and for hairy vetch and faba-bean higher yield obtained from relay-intercropping. Similarly, based on field observation during the season, rather than planting sole lablab followed by maize-inter cropping, it is better planting maize-bean intercropping then sole lablab crop within the same season. Considering only bean biomass collected from the first and second round planting in 2016, double cropping that is lablab under sole cropping followed by maize-bean intercropping (Lablab then maize + bean) within a season had the highest biomass yield averaging 9414 kg/ha and followed by relay cropping (maize + bean + bean) which had 7703 kg/ha (Table 3).

Based on the equivalent conversion of bean yield into maize grain yield and the sum of value with maize grain yield obtained directly from the same treatments, the highest maize grain yield (10021 kg/ha) was obtained from relay cropping in 2016 compared with the other cropping systems (Table 5). This is consistent with findings by Paudel (2001) who reported relay cropping of finger millet with maize in mid hills of Nepal is the most important inter cropping compared with different forms of multiple cropping at areas where there is limitation for farm land and it gives the chance to enhance production in short period. Daniel (2019) also reported higher grain

Table 3. Mean performance of cropping systems for each season, each planting round and sum of value from each planting round with in the season of maize and bean for grain yield and biomass.

Cropping system	Grain yield ($kgha^{-1}$)							
	1st Bean and maize planting in 2015		1st Bean and maize planting in 2016		2nd Bean and maize planting in 2016		Sum of mean performance 1st and 2nd planting (2016)	
	Bean	Maize	Bean	Maize	Bean	Maize	Bean	Maize
Sole maize (CN)	-	1453	-	4215	-	-	-	4215
Sole maize (CA)	-	1444	-	3557	-	-	-	3557
Double cropping (maize after bean) under CA	2618	-	3149	-	-	-	3149	-
Double cropping (bean after maize) under CA	-	1337	-	3677	2107	-	2107	3677
Relay (maize + bean) + (bean) under CA	1263	972	1729	2626	1353	-	3081	2626
Lablab then (maize + bean) under CA	-	-	-	-	2038	-	2038	-
Cropping system	**Biomass (kg/ha)**							
	Bean	Maize	Bean	Maize	Bean	Maize	Bean	Maize
Sole maize (CN)	-	7409	-	9324	-	-	-	9324
Sole maize (CA)	-	6854	-	8363	-	-	-	8363
Double cropping (maize after bean) under CA	4427	-	4899	-	-	-	4899	-
Double cropping (bean after maize) under CA	-	7118	-	16050	4338	-	4338	16050
Relay (maize + bean) + (bean) under CA	1507	5980	4466	5568	3237	-	7703	5568
Lablab then (maize + bean) under CA	-	-	5410	-	4004	-	9414	-

yield of relay cropping from treatments tested under CA. The second-high yielding cropping system was double cropping (bean after maize) with 8735 kg/ha (Table 5). Considering the cropping systems with other crops, Chavan et al. (2018) reported the highest system productivity in terms of rice equivalent grain yield in case of rice-brinjal (239.12 q/ha) sequence. Regarding the biomass (sum of maize and bean biomass obtained from both planting round in 2016), double cropping (bean after maize) had the highest value (20388 kg/ha) and followed by relay cropping (13271 kg/ha) (Figure 2). In line with this finding, Solomon (2018) reported higher yield of 17% obtained from cowpea-maize double cropping than continuous short maturing maize mono-cropping. Further the author reported higher biomass production performance (22-36%) by this cropping system compared with other cropping systems. The results in Table 4 show that relay cropping was out- performed by sole maize under CA (182%) and conventional practice (138%) for maize grain yield considering bean equivalent and also including maize grain yield harvested directly from the treatment. Double cropping (maize then bean) also had the highest production efficiency advantage over sole maize under CA with the value of 146% higher. It also had 107% production efficiency advantage over conventional sole maize. Double cropping (maize after bean) had higher production efficiency than sole maize under CA, conventional sole maize and lablab then maize-bean inter-cropping systems. Regarding biomass, maize followed by bean double cropping had higher production efficiency compared with the rest of the cropping systems. Double cropping (bean after maize) had 316% biomass production efficiency than double cropping (maize after bean). The production efficiency of biomass from relay cropping was also 35% higher in the four cropping systems than maize followed by bean cropping systems. Generally, the positive production efficiency values figures indicate better production efficiency of new cropping systems compared with the conventional method (Table 4). The variance between cropping systems was significant for maize equivalent conversion of bean grain yields into maize plus value of maize grain

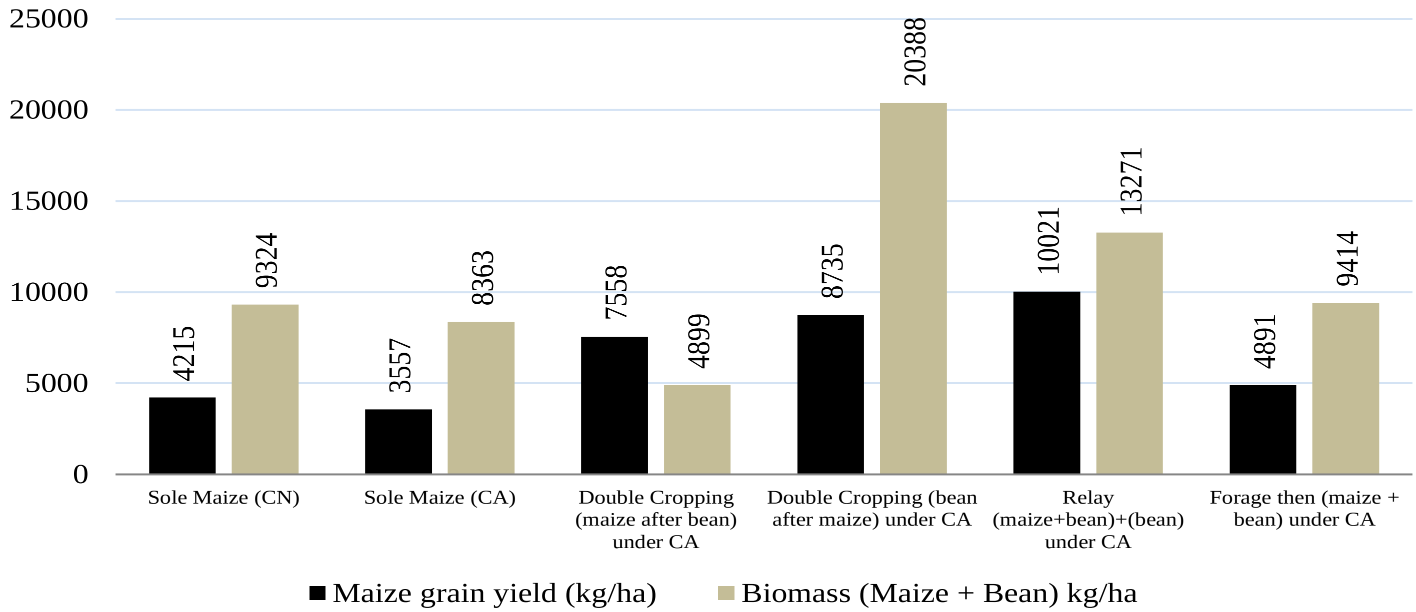

Figure 2. Maize grain (considering bean grain yield equivalent conversion into maize yield for plot which had common bean yield data) and total biomass yield from the plot (maize and bean biomass added together) the result obtained from first and second round planning added in 2016.

Table 4. Relative production efficiency of cropping systems listed in rows over the other cropping systems listed in vertical column for grain yield of maize after equivalent conversion of bean grain yield in to maize grain yield and addition of maize and bean biomass considering both 1st and 2nd planting round in 2016.

Cropping system	Grain yield			Biomass yield	
	Relay (Maize + Bean) + (Bean) Under CA	Double Cropping		Double Cropping	Relay (Maize + Bean) + (Bean) under CA
		(Bean after maize) under CA	(Maize after bean) under CA	(Bean after maize) under CA	
Sole maize (CN)	138	107	79	119	42
Sole maize (CA)	182	146	113	144	59
Double cropping (maize after bean) under CA	33	16	-	316	171
Double cropping (bean after maize) under CA	15	-	-14	-	-35
Relay (maize + bean) + (bean) under CA	-	-13	-25	54	-
Lablab then (maize + bean) under CA	105	79	55	117	41

Table 5. Production efficiency of cropping systems for maize grain yield (kg/ha) considering equivalent conversion of bean grain yield in to maize grain yield and biomass yield (bean and maize biomass added together and both planting round results added) in for season 2015 and 2016.

Cropping system	2015		2016	
	Grain	Biomass	Grain	Biomass
Sole maize (CN)	1453^{c}	7409^{ab}	4215^{c}	9324^{bc}
Sole maize (CA)	1444^{c}	6854^{ab}	3557^{c}	8363^{bc}
Double cropping (maize after bean) under CA	6283^{a}	4427^{b}	7558^{b}	4899^{c}
Double cropping (bean after maize) under CA	1337^{c}	7118^{ab}	8735^{b}	20388^{a}
Relay (maize + bean) + (bean) under CA	4003^{b}	7487^{a}	10021^{a}	13271^{b}
Lablab then (maize + bean) under CA	-	-	4891^{c}	9414b^{c}
CV (%)	13.9	24.3	26.1	25.2
F-test	***	ns	***	***

Table 6. Water use efficiency (kgmm^{-1}) by cropping systems of common bean in kg per mm of rainfall for grain yield and biomass production in 2015 and 2016.

Cropping system	1st round planting in 2015		1st Bean planting in 2016		2nd Bean planting in 2016		Sum of output from 1st and 2nd planting time	
	GY	BIOM	GY	BIOM	GY	BIOM	GY	BIOM
Double cropping (maize after bean) under CA	9^{a}	15^{a}	8^{a}	12^{a}	-	-	8	12
Double cropping (bean after maize) under CA	-	-	-	-	9^{a}	19^{a}	9	19
Relay (maize + bean) + (bean) under CA	4^{b}	5^{a}	4^{b}	11^{a}	6^{b}	14^{a}	10	25
Lablab then (maize + bean) under CA	-	-	-	13a	9a	17a	9	30
CV (%)	5.7	32.5	14.8	11.8	12.6	30.5	-	-
F-test	***	ns	*	ns	*	ns	-	-

GY=Grain yield; BIOM=Biomass.

Table 7. Rain water use efficiency (kg mm^{-1} rainfall) maize grain yield and biomass yield for different cropping systems in 2015 and 2016 copping systems at Hawassa.

Cropping system	2015		2016		Across seasons	
	Grain	Biomass	Grain	Biomass	Grain	Biomass
Sole Maize (CN)	4^{a}	18^{a}	8^{a}	17^{b}	6^{a}	17^{ab}
Sole Maize (CA)	3^{a}	16^{a}	6^{a}	15^{b}	5^{a}	16^{b}
Double (bean after maize) under CA	3^{ab}	17^{a}	7^{a}	29^{a}	5^{a}	23^{a}
Relay (maize + bean) + (bean) under CA	2^{b}	14^{a}	5^{b}	10^{b}	4^{b}	12^{b}
CV	16.4	26.1	12.2	30	16.6	27.7
Cropping system (CS)	ns	ns	*	*	**	*
Season (S)	-	-	-	-	***	Ns
CS * S	-		-	-	ns	*

yield in 2015 and 2016. Cropping systems had a significant effect on biomass production in 2016, but not in 2015 (Table 5).

Water use efficiency

There was significant water use efficiency difference between double cropping yield and relay cropping in 2015 and 2016 from first round planting of common bean (Table 6). A similar trend was observed at second round planting. However, no water use difference was observed for biomass in both years and planting times. The total water use efficiency biomass from first and second round planted common bean was highest for maize bean inter cropping after lablab (30 kg mm^{-1}) followed by maize-bean inter-cropping with a value of 30 kg mm^{-1}, followed by relay cropping 25 kg mm^{-1} (Table 6). In contrast, the highest water use efficiency for grain yield was observed from relay cropping (10 kg mm^{-1}) followed by double cropping (bean after maize) 9 kg mm^{-1} (Table 6). The results from this study indicated that relay cropping helps to increase the water use efficiency of grain yield at Hawassa and similar environments in the Central Rift Valley of Ethiopia. This highlights the need to develop cropping system that increase rainwater and land productivity in the area to increase food security in the region.

Water use efficiency for biomass was significantly different among cropping systems in both seasons while it was significant for grain yield only in the 2015 cropping season (Table 7). When combined over seasons, significant difference was observed among cropping systems for both grain and biomass yield. Season had significant effect on water use efficiency of grain yield but not biomass. Cropping system by season interaction was significant for biomass but not for grain yield. In 2015, water use efficiency for maize grain yield was similar for sole maize under conventional practice (4 kg mm^{-1}) and sole maize under CA (3 kg mm^{-1}). Similarly, sole maize under conventional practice had slightly higher water use efficiency (18 kg mm^{-1}) and followed by double cropping (maize then bean) under CA (17 kg mm^{-1}) for biomass. In 2016, for grain yield, the highest water use efficiency was obtained from sole maize under conventional practice and followed by double cropping (bean after maize). However, for biomass, the highest water use efficiency was obtained from double cropping (maize then bean)

Table 8. Maize grain and biomass yield water use efficiency (kg mm^{-1} of rainfall) for cropping systems considering equivalent bean conversion into maize for production efficiency and biomass production (sum of maize bean biomass) in the 2015 and 2016 cropping season at Hawassa.

Cropping system	2015		2016	
	Grain	Biomass	Grain	Biomass
Sole maize (CN)	4[c]	18[ab]	7[b]	14[bc]
Sole maize (CA)	3[c]	16[ab]	5[b]	13[bc]
Double cropping (maize after bean) under CA	15[a]	11[b]	13[a]	9[c]
Double cropping (bean after maize) under CA	3[c]	17[ab]	13[a]	31[a]
Relay (maize + bean) + (bean) under CA	10[b]	18[a]	14[a]	19[b]
Lablab then (maize + bean) under CA	-	-	8[b]	14[bc]
CV (%)	13.9	24.3	26.1	25.2
F-test	***	ns	***	***

(29 kg mm^{-1}) under CA and followed by sole maize under conventional practice (17 kg mm^{-1}). Across seasons, the least grain yield water use efficiency was observed for relay cropping while no difference was observed among other cropping systems. However, the highest water use efficiency for biomass was obtained from double cropping (maize then bean) under CA (23 kg mm^{-1}) followed by sole maize under conventional practice (17 kg mm^{-1}) (Table 7). A previous study by Micheni et al. (2014); however, reported no significant difference in WUE for grain yield for cropping systems evaluated under CA and CN in Kenya.

Results of water use efficiency based on maize yield equivalents of beans and the maize yields for each treatment are summarized in Table 8. In 2015, for cropping systems the variance showed significant effect on grain yield and the highest water use efficiency was obtained from double cropping (maize then bean) (15 kg mm^{-1}) followed by relay cropping 10 kg mm^{-1}. The water use efficiency of double cropping (bean then maize) exceeded the WUE of sole maize under CA and sole maize under conventional practice by 326%. The relay cropping was also outperformed by these two treatments by 171%. The water use efficiency of double cropping (bean then maize) and relay cropping was higher than double cropping (maize then bean) by 366 and 197% in 2015 for grain yield. However, for biomass, relay cropping under CA and sole maize under conventional practice had equal water use efficiency (18 kg mm^{-1}). In 2016, the water use efficiency variance between the cropping systems was highly significant for both grain and biomass yields. For grain yield, the three cropping systems namely double cropping (bean then maize), double cropping (maize then bean) and relay cropping had similar WUE. Solomon (2018) also reported higher grain yield from cowpea-maize double cropping systems during spring and water use efficiency than at summer repeated planted maize mono-cropping. These cropping systems also had greater water use efficiency over sole maize under conventional practice, sole maize under CA and lablab then maize-bean inter-cropping under CA by 109, 152 and 81%, respectively. The highest biomass water use efficiency was observed from double cropping (maize then bean) (31 kg mm^{-1}) followed by relay cropping (19 kg mm^{-1}) (Table 8). This is in line with the higher water use efficiency of multiple cropping than mono-cropping due to soil cover by the crop during the vegetative stage (Greenland and Lal, 1977; Siddoway and Barnett, 1976). The least WUE of biomass was obtained from double cropping (maize after bean) (9 kg mm^{-1}). Double cropping (maize then bean) had higher WUE than sole maize under conventional, sole maize (CA), Double Cropping (Bean then Maize) under CA, Relay (Maize + Bean) + (Bean) Under CA and Lablab then (Maize + Bean) under CA (118, 144, 259, 63 and 117%), respectively. Relay cropping also had higher WUE than sole maize under conventional, sole maize (CA), Double Cropping (Maize after Bean) under CA and (Maize + Bean inter cropping) after lablab under CA (34, 49, 120 and 33%), respectively.

Conclusion

The overall assessment of cropping systems under CA and CN indicating that, considering bean yield equivalent to maize and the addition of maize harvest direct from relay cropping performed better than the other cropping systems tested. For biomass production (sum of the value of maize and bean), double cropping (bean after maize) was the best cropping strategy under the Central Rift Valley conditions of Ethiopia. The higher grain and biomass yield, and water use efficiency obtained from relay cropping and double cropping highlights the need for use of multiple cropping to enhance yields of component crops than monocropping. Double cropping systems utilized rainwater more efficiently than mono-cropping practices. Applying double cropping (bean after maize), maize-bean relay cropping (maize + bean) + bean) and lablab then maize-bean inter cropping are appropriate cropping strategies than planting single crops under both CA and CN in order to enhance land and water productivity in the region. Based on our observation, planting lablab under sole crop after maize + bean inter cropping (main crops) is advisable rather than planting forage crop first then maize + bean inter cropping. This is of paramount importance for areas characterized by high family size and small land holdings.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Abaineh E, Ashenafi A, Demeke T (2006). Soils of the Farmland of Awassa Agricultural research center and its testing sites, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia.

Alene AD, Manyong VM, Gockowski J (2006). The production efficiency of intercropping annual and perennial crops in southern Ethiopia: A comparison of distance functions and production frontiers. Agricultural systems 91(1-2):51-70. Doi: 10.1016/j.agsy.2006.01.007.

Bezabih M, Sarr M (2012). Risk preferences and environmental uncertainty: Implications for crop diversification decisions in Ethiopia. Environmental and Resource Economics 53(4):483-505.

Cairns JE, Crossa J, Zaidi P, Grudloyma P, Sanchez C, Araus JL, Thaitad S, Makumbi D, Magrokosho C, Bänziger M, Menkir A, Hearne S, Atlin GN (2013). Identification of drought, heat, and combined drought and heat tolerant donors in maize. Crop Science 53(4):1335-1346.

Central Statistical Agency (CSA) (2017). Report on area and production of major crops for private peasant holdings (Meher season). Statistical bulletin 584, Agricultural sample survey volume 1, Addis Ababa, Ethiopia.

Chavan AP, Sonone NG, Jadhav MS, Sagvekar VV (2018). Identification of Profitable Rice Based Cropping System for South Konkan Coastal Zone. International Journal of Current Microbiology and Applied Sciences 7(10):289-296.

Chikowo R, Mapfumo P, Leffelaar PA, Giller KE (2006). Integrating legumes to improve N cycling on smallholder farms in sub-humid Zimbabwe, resource quality, biophysically and environment limitations. Nutrient Cycling in Agroecosystems 76:219-231.

Conway D, Schipper ELF (2011). Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. Global Environmental Change 21(1):227-237.

Daniel M (2019). Conservation agriculture based inter cropping and relay cropping of maize with legumes at Hawassa, Southern, Ethiopia. In: Legesse Hindo, Daniel Markos, Waga Mazengia, Abay Ayalewu and Alemayehu Balcha, towards sustainable maize legume cropping systems: Conservation Agriculture based intensification. Work shop proceeding of conservation-based intensification, Shashemene, Ethiopia pp. 105-126.

Demeke M, Guta F, Ferede T, Ababa A (2004). Agricultural development in Ethiopia: are there alternatives to food aid? Department of Economics, Addis Ababa University. www. sarpn. org. za/documents/d0001583/FAO2005_Casestudies_Ethiopia. pdf.

Getahun D, Tenaw W (1990). Initial results of informal survey Areka Area Mixed Farming Zone Welayita Awraja; Sidamo Region. Institute of Agricultural Research. Working Paper.

Gliessman SR, Garcia RE, Amador MA (1980). The Ecological Basis for the Application of Traditional Agricultural Technology in the Management of Tropical Agroecosystems, submitted to Agro-Ecosystems.

Greenland DJ, Lal R (1977). Soil conservation and management in the humid tropics. Chichester: John Wiley.

Kamanga BCG, Waddington SR, Robertson MJ, Giller KE (2009). Risk Analysis of Maize-Legume Crop Combinations with Smallholder Farmers Varying in Resource Endowment in Central Malawi. Experimental Agriculture 46(1):1.

Karim M, Fracheboud Y, Stamp P (2000). Effect of high temperature on seedling growth and photosynthesis of tropical maize genotypes, Journal of Agronomy and Crop Science 184:217-223.

Love D, Twomlow S, Mupangwa W, van der Zaag P, Gumbo B (2006) Implementing the millennium development food security goals–Challenges of the southern African context. Physics and Chemistry of the Earth, Parts A/B/C 31(15-16):731-7.

Marinus W (2014). Cowpea-maize relay cropping: A method for sustainable agricultural intensification in northern Ghana? MSc thesis (minor), PPS 80433.

McHugh OV, Steenhuis TS, Abebe B, Fernandes E (2007). Performance of in situ rainwater conservation tillage techniques on dry spell mitigation and erosion control in the drought-prone North Wello zone of the Ethiopian highlands. Soil and Tillage Research 97(1):19-36.

Micheni AN, Kanampiu, F, Kitonyo O, Mburu D, Mugai EN, Makumbi D, Kassie M (2014). On-farm experimentation on conservation agriculture in maize-legume based cropping systems in kenya: water use efficiency and economic impacts, Experimental Agriculture. Cambridge University Press 1:18.

Osman M, Sauerborn P (2002). A preliminary assessment of characteristics and long-term variability of rainfall in Ethiopia–Basis for sustainable land use and resource management. Challenges to Organic Farming and Sustainable Land Use in the Tropics and Subtropics, Deutscher Tropentag.

Paudel MN (2001). Findings of participatory rural appraisal survey conducted in the high hills of Dhankuta, Dolkha, Myagdi and Dailekh districts, ARSP Working paper No 255, ISSN 1021-5034.

Ritchie J, Singh U, Godwin D, Hunt L (1989). A User's Guide to CERES Maize-V2.10. International Fertilizer Development Center, Muscle Shoals, Alabama 35662, U.S.A. Second Edition.

Rockström J, Kaumbutho P, Mwalley J, Nzabi A, Temesgen M, Mawenya L, Barron J, Mutua J, Damgaard-Larsen S (2009). Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. Soil and Tillage Research 103 (1):23-32.

Rurinda J, Mapfumo P, van Wijk MT, Mtambanengwe F, Rufino MC, Chikowo R, Giller KE (2014). Comparative assessment of maize, finger millet and sorghum for household food security in the face of increasing climatic risk. European Journal of Agronomy 55:29-41.

Samant TK (2015). System productivity, profitability, sustainability and soil health as influenced by rice-based cropping systems under mid central table land zone of Odisha. International Journal of Agriculture Sciences 7(11):975-9107. ISSN:0975-3710&E-ISSN.

Sandler L, Nelson KA (2016). Inter- and Double-crop Yield Response to Alternative Crop Planting Dates, www.todayscience.org/as Agricultural Science 4(2).

Sankaranarayanan NP, Praharaj CS (2012). Multi-tier cropping system to enhance resource utilization, profitability and sustainability of Bt cotton (Gossypiumhirsutum) production system. Indian Journal of Agricultural Sciences 82(12):1044-50.

Seyoum S, Chauhan Y, Rachaputi R, Fekybelu S, Prasanna B (2017). Characterizing production environments for maize in eastern and southern Africa using the APSIM Model. Agricultural and Forest Meteorology 247:445-53.

Shiferaw B, Tesfaye K, Kassie M, Abate T, Prasanna BM, Menkir A (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. Weather and Climate Extremes 3:67-79.

Siddoway FH, Barnett AP (1976). Water and Wind Erosion Control Aspects of Multiple Cropping, In: Papen dick, R. I., et al., Multiple Cropping, ASA Special Publ. No, 27:317.

Solomon JH (2018). Risks and opportunities from more productive and resilient cropping system strategies in the Central and Southern Rift Valley of Ethiopia, PhD Thesis. Queensland Alliance for Agriculture and Food Innovation (QAAFI), Queensland.

Statistical Analysis System (SAS) institute (2002). The SAS system for windows. Version 9.0. SAS Inst., Cary, NC.

Tesfaye K, Walker S (2004). Matching of crop and environment for optimal water use: the case of Ethiopia. Physics and Chemistry of the Earth, Parts A/B/C, 29(15-18):1061-7.

Tesfaye K, Seid J, Getnet M, Mamo G (2016). Agriculture under a Changing Climate in Ethiopia: Challenges and Opportunities for Research. no. EIAR 50th Year Jubilee Anniversary Special Issue, pp. 67-86.

Walelign W (2014). Sequential intercropping of common bean and mung bean with maize in southern Ethiopia. Cambridge University Press 50(1):90-108.

Workayehu T (2014). Legume-based cropping for sustainable production, economic benefit and reducing climate change impacts in southern Ethiopia. Journal of Agricultural and Crop Research 2(1):11-21.