Identification of Best Maize-Legume Based Cropping Systems under Conservation Agriculture Practices for Central Rift Valley of Ethiopia

M. Goshime[1], W. Mupangwa[2], Z. Alemayehu[1], B. Haimanot, H. Mesele, A. Mahmud
1. Ethiopian Institute of Agricultural Research, Hawassa Maize Research Sub-Centre, PO Box 845, Hawassa, Ethiopia
2. International Maize and Wheat Improvement Center (CIMMYT), Shola Campus, ILRI, PO Box 5689, Addis Ababa, Ethiopia
* Corresponding author: goshime.muluneh@yahoo.com

Abstract
The term cropping system refers to the crops and crop sequences and the management techniques used on a particular field over a period of years. This experiment was conducted at Hawassa Research Centre. The experiment was run for two years (2015-2016).The experiment consisted of six treatments (Continuous mono-cropping under conventional practice (CN) and Continuous mono cropping (CA), relay cropping with double bean planting within a season under CA (maize bean inter-cropping: second round bean planting was conducted after immediate harvesting of the first bean), Double cropping (lablab then maize bean inter cropping), Double cropping (bean then maize) under CA and Double cropping (maize then bean) under CA. Maize yield and yield related traits and soil water data were collected from each treatment. In 2016, the highest maize biomass yield of 16050 kg ha^{-1} was obtained from double cropping and the maximum water use efficiency was also from the same treatment and averaged 31kg mm^{-1}. Maize-bean relay cropping outperformed the sole maize under CA and conventional practice by 182 and 138 % for maize grain yield from bean equivalent conversion into maize and grain yield inclusion of direct harvest in 2016.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. For biomass, relay cropping under CA and sole maize under conventional practice had similar water use efficiency averaging 18 and 18 kg mm^{-1}, respectively. For grain yield double cropping (bean then maize), double cropping (maize then bean) and relay cropping under CA had greater water use efficiency than sole maize under conventional practice, sole maize under CA and lablab then maize-bean inter cropping under CA, averaging 109, 152 and 81%, respectively. The result showed use of CA practice with diverse crops planted together (maize and bean): double inter-cropping at different time (relay cropping) and double cropping under CA (maize then bean) are good strategies to use the residual soil moisture and to improve crop productivity in the sustainable way as compared with the conventional sole planting.
Keywords: Cropping system, lablab, water use efficiency
DOI: 10.7176/JNSR/13-15-04
Publication date: September 30th 2022

Introduction

Ethiopia's socio-economic basis is rural farming and agriculture is a key driver of the country's long-term growth and food security (Musa, 2014). About 85% of the population is in rural parts of the country and agriculture directly supports 83% of the population, constitutes 41% of Gross Domestic Product (GDP), and 90% of export value (EEA (Ethiopian Economic Association), 2012). However, complex and wide spread poverty, food insecurity, low productivity, famine and degradation of natural resources are among the challenges facing the country (David et al., 2011).

In Ethiopia, agriculture remains the most important sector of the economy (Lupi and Kibert, 2019). In the semi-arid Rift Valley regions of Ethiopia, rain-fed farming systems are challenged by climate variability and associated risks. Although the region has an inherent vulnerability, it has great potential and opportunities to enhance crop productivity and resilience (Solomon, 2018). Currently, farmers' low resource capacity and largely risk-aversion attitude means these opportunities are missed and huge productivity and resilience gaps exist. The gaps could be narrowed, and food security achieved by utilizing available resources along with resilient cropping systems and strategies. Projected changes in rainfall and temperature are expected to cause increased drying and droughts in important agricultural production areas of the world (Dai, 2013). Depending on the severity of these changes, a number of adaptations will be required to maintain global agricultural production levels, the attributes of soil moisture conservation and water use efficiency and conservation agriculture could play an important role.

The term cropping system refers to the crops, crop sequences and the management techniques used on a particular field over a period of years. The emergence of systems' approach has enabled increased production without damaging the resource base by making effective use of inputs such as soil, water, fertilizer, land and labor, capital, the factors of production as a whole.(Mina, 2016). There is every possibility of saving resources following systems' approach in cropping (Rana and Rana, 2011). Cropping system is a commonly and broadly used word to explain a more integrated approach to cropping as compared to monoculture approaches. Mono-cropping is exception, while mixture (of species) is the rule of nature and it is an intensive agricultural system often based on optimizing the productivity of monocultures (Sankaranarayanan et al., 2012). In those systems, crop diversity is reduced to one or very few species that are generally genetically homogeneous, the planting layout is uniform and symmetrical, and external inputs are often supplied in large quantities (Malezieuxn *et al.*, 2007). Cropping systems based on biodiversity and sustainable soil management (e.g. agro-forestry, conservation agriculture), and using less (or no) chemical inputs (organic farming) could result in a positive compromise between food production, adaptation and mitigation to climate change. Establishing climate-smart and resilient cropping systems may involve the implementation of integrated strategies comprised of relevant sets of management practices rather than implementing specific practices one at a time (Debaeke *et al.,* 2017).

Multiple cropping has been practiced in many parts of the world as a way to maximize land productivity in a specific area in a growing season (Glassman and Amador 1979;Wilken, 1974; Mina, 2016). It is an agricultural system long adopted by marginalized smallholder farmers especially in hilly and mountainous areas and is meant to enhance farm productivity when farming area is limited (Mina, 2016). Multiple cropping is the practice and an efficient utilization of production resources like water, light, space and nutrients by companion crops in both temporal and spatial dimensions due to their differential growth habits and seasonality (Mina, 2016). Multiple cropping could be one of the viable options to cope with uncertainties and changes, where food and nutritional uncertainty are looming large. In the tropics, smallholder farms, which produce over 60% of the food resources of developing nations from intercropping of cereals with many crops mostly legumes, have been the field of much investigation because of synergistic effects of diversifying food production and household cash incomes in these systems (Mina, 2016; McDonald et al., 2019). This clearly indicates the role of multiple cropping for smallholder farmers who are the majority of food producers in the developing countries. Generally, the practice of planting two or more crops on the same field is more common in tropical regions where rainfall and temperatures are high, and longer growing seasons are more favorable for continual crop production. As the human population has increased, increasing the need for agricultural production, the use of multi-cropping systems is more critical now than before. Though the history of multiple cropping is old, the concept has received very little attention from agricultural research scientists and what limited interest exists has come about very recently.

The researchers try to combine two or more crops simultaneously in one area, and there exists the possibility of complex interactions between the plants and their soil environment (Sanchez, 1976).When total complementarily is achieved, the roots of the component species occupy different soil horizons, reducing considerably the potential competition between species and increasing the efficiency of total nutrient uptake (Stephen, Chapter-V). In combinations of deep-rooted with shallow-rooted species, especially when trees are planted with grasses or annual crops, the trees are capable of absorbing un-captured nutrients as they are leached into the soil (Chikowo et al., 2006). Then, through their transport to foliage, they can be deposited on the soil surface again as the leaves drop (Zinke, 1962).Total biomass production, as well as yield removed from the system, is considerably higher from the crop mixture.

In multiple cropping systems, especially with several crops of differently arrayed root systems, a greater volume of the soil is typically occupied and thus water use efficiency is higher. This is useful, on the one hand, in areas where water supplies are limited. It also helps make more complete use of costly irrigation water. It has been proposed that cover crops in orchards stimulate deeper rooting by the trees (Baldy, 1963).Different peak periods of water use in the crop mixtures would avoid competition and increase overall water use efficiency (Baker and Norman, 1975). A crop such as maize (*Zea mays* L.) that uses relatively little water in its early stages of development could be inter-planted with an early maturing crop that could take advantage of the unused soil moisture (Kassam and Stockinger, 1973).

The important effects of multiple cropping on the conservation of water and soil are primarily achieved through the maintenance of a more complete vegetative cover over the soil (Greenland and Lal, 1977; Siddoway and Barnett, 1976).It is important to remember that apart from improving soil cover while the crop is growing, multiple cropping systems aim towards maintaining this cover between harvests. This is achieved by reducing the time between harvest and replanting in sequential systems, planting a new crop into another in relay cropping, and continually inter-planting in an intercropped system. Although it appears that multiple cropping systems use more water, their ability to obtain water that cannot be accessed in monoculture systems, use the water more efficiently, and contribute significantly to soil conservation, demonstrate a further potential for their more widespread use in smallholder cropping systems of sub-Saharan Africa.

Identification of the best cropping systems under conservation agriculture practices for optimum grain yield and biomass production of maize and legume crop is critical in the Central Rift Valley of Ethiopia. This study was designed to assess the effects of six different cropping mixtures on maize and bean yields. The six mixtures were (a) continuous mono-cropping under conventional practice, (b) continuous mono cropping under CA, (c) relay cropping with double bean inter cropping at different time within a season under CA, (d) double cropping (CA) (maize then bean within a season), (e) double cropping (CA) (bean then maize within a season) and (f) Double cropping (CA) (lablab then maize-bean inter cropping).

2. Method and Material

2.1. Description of the study area

The experiment was carried out at Hawassa Research Station (located at 38°30'88 E, 07°03'71 N, and 1689masl) in Ethiopia during 2015to 2016 main cropping seasons under rain-fed condition. These two seasons received total rainfall amount of 671 and 985 mm in 2015 and 2016, respectively. This location is characterized by bimodal rainfall pattern with extended rainy season from March to September. Rainfall totals for some of the years are summarized in Figure 1. The mean, annual maximum and minimum temperatures are 27.3ºC and 12.6ºC, respectively. The soil type of the land is defined as vitric Andosols with 80-152 cm depth and its slope ranges from 0-2% (Abaineh *et al.,* 2006). The soil is slightly acidic to neutral with the top soil (0-30 cm) pH with values ranging between 6.4 and 6.9.Cropping systems used in the Hawassa smallholder farming area is continuous sole maize under conventional ploughing practice.

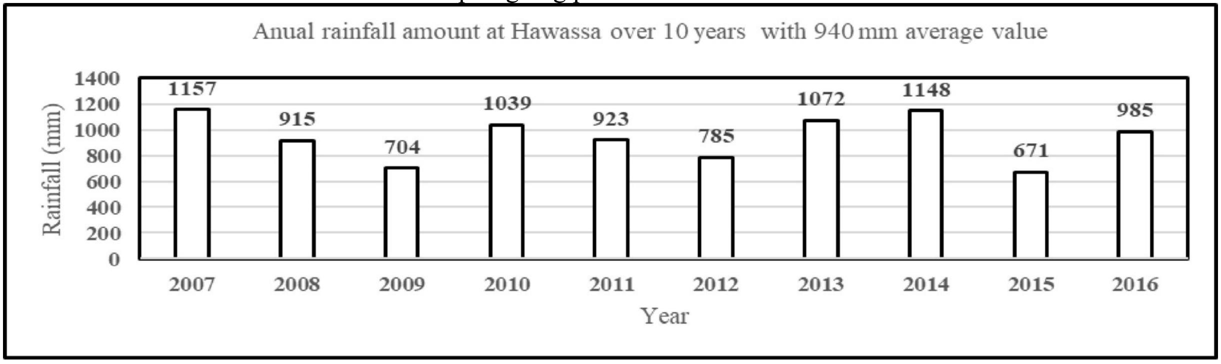

Figure1. Long term rainfall data at Hawassa area along the Central Rift Valley of Ethiopia

2.2. Description of treatments and experimental set up

Six treatments comprising five cropping systems under conservation agriculture and one conventional practice were laid out in a randomized complete block design (RCBD) with three replications. The six treatments tested during experimentation are described below;

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

In the CA treatments, narrow rows were opened with a hand-hoe to a depth of about 10 cm to place seeds and basal fertilizer application without any prior tillage. The conventional tillage practice (CN) was cultivated similar to the traditional land preparation practice of farmers planting maize and common beans at Hawassa. Land is prepared by conventional ploughing with an ox-drawn traditional plough called Maresha just before planting. Each plot consisted of six rows of 3.6m long. Maize was planted at a spacing of 75 cm inter-row and 30 cm intra row while common bean (*Phaseolus vulgaris* (L.)) was planted at 40 cm between rows and 10 cm inter-plant density. Two seeds were planted per hill and thinned to one plant at two weeks after emergence to a desired plant population of 44444 plants ha^{-1} for maize and 250000 plants ha^{-1} for common bean.

2.3. Experimental management

The recommended fertilizer rates at Hawassa namely 110 kg N and 46 kg P_2O_5 ha^{-1}, were applied to all treatments with maize. All phosphorous and one-third of the N fertilizer was applied at planting and the remaining two-thirds of N was side-dressed between 25 and 35 days after maize emergence (V5-V8 stage) (Ritchie et al., 1989). For common bean, 46 kg P_2O_5 and 37 kg of N ha^{-1} was applied at planting. 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 in intercrop treatments the bean was planted between maize rows. Initial weed control in CA treatments was achieved by spraying with a broad-spectrum systemic herbicide (glyphosate) seven days before planting at 3-liters ha^{-1} and all plots were maintained weed free afterwards by hand weeding 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. In the CN treatments, managed similar to the common farmers' practice, crop residues were cut and carried for feed and fuel immediately after harvesting.

2.4. Agronomic measurements and statistical analysis

Above-ground biomass, grain yield, stand count at harvest and phonological data such as anthesis, silking and maturity were recorded for maize, while grain and biomass yields, number of pods per plant, number of seeds per pod and thousand seed weight were recorded for common bean. The rainfall water use efficiency, i.e. kg grain and biomass per mm rainfall, was calculated. Ten maize and common bean plants were cut at the ground level for sampling. From ten samples maize plant, 0.5 kg sub sample and the whole ten common bean plants dried for 72 hours at 70o C for dry weight measurement (Karim et al., 2000). Maize and common bean yields were adjusted to 12.5 and 10 % grain moisture content, respectively, and expressed on a ha basis. The data was analyzed using SAS version 9.0. Data were analyzed following a randomized complete block design experiment (Gomez and Gomez, 1984). Before water use efficiency computation, grain yield of common bean was converted into maize grain yield considering the amount of birr generated from bean and how much maize grain yield can purchase using that many. Finally, the maize grain yield harvested from the plot directly and obtained from the conversion was added for the plot which had both maize and bean crop together. For each season, cropping system was used as factor whereas for combined analysis cropping system and season were the factors. The effect of cropping system and season were tested against mean square error for individual location and combined analysis. Mean square of error was also used as error term to test treatment*season interaction effect.

$$\text{Water Use Efficiency for grain yield} = \frac{\text{Grain yield produced}}{\textit{rain water (mm) obtained from planting up to maturity}} \quad (1)$$

2.5. Production efficiency

Production efficiency of new crop management practices has been measured through many indices. Crop equivalent yield (CEY) and relative production (RPE) have been among the recent approaches used for evaluating the production efficiency of cropping systems (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 (RPE %) and Crop equivalent yield (CEY). Before calculating the RPE, first the average yield of the component crops was converted into maize equivalent yield (MEY) on a price basis following Sankaranarayanan et al. (2012) and Samant (2015).

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

Where, MEY is maize equivalent yield; Y is the yield of common bean (kg ha^{-1}), 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}), respectively during their production years.

For calculating the equivalent yield in terms of crop equivalent yield, maize yield and maize equivalent yield of legume crops were summed up and expressed as t ha^{-1}. Thus, the RPE% of the system was calculated following Sankaranarayanan *et al.* (2012) as presented in Equation 3:

$$\text{RPE\%} = \left(\frac{\text{CEYD} - \text{CEYE}}{\text{CEYE}}\right) * 100 \quad (3)$$

Where, RPE is relative production efficiency; CEYD is the crop equivalent yield under improved system and CEYE is the equivalent yield under existing cropping system (conventional practice).

The inference was that positive figures showed the superiority of the new system over the existing and desirable while negative figures showed inferiority over the existing system and not desirable.

3. Results and Discussion

3.1. Performance of different cropping systems

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). Seasons had significant effects on the measured parameters. The season x treatment interaction had significant effects on dry biomass yield and HI, indicating the cropping systems had inconsistent performance across the seasons. The cropping system x season interaction had no significant influence on grain yield indicating that, the cropping systems effects were similar during the two seasons. In 2016, the highest maize grain yield was obtained from conventional practice, followed by double cropping (maize then bean). Similar performance was observed from these treatments across the seasons. In 2016, the highest biomass yield (16050 kg ha^{-1}) was obtained from double cropping (maize-bean), followed by conventional practice which had 9324 kg ha^{-1}. Across the years, double cropping (maize then bean) and sole maize under conventional practice had high biomass yield with the magnitude of 11584 and 8366 kg ha^{-1}, respectively which is relatively higher as compared with the remaining four cropping systems included in the this experiment (Table 1). The higher bean grain and biomass yields were obtained from double cropping (bean then maize) and relay cropping in 2016 compared with results from 2015 based on first round planting. Bean grain yield from double cropping (bean then maize) was higher by 20% in 2016 than 2015. Bean grain yield produced in 2016 from relay cropping was 37% higher compared with grain yield obtained in 2015 from first round planting (Table 2).

Table1. Comparison of cropping systems for maize grain yield and other traits in experiment tested in 2015, 2016 and combined analysis.

Year	Cropping system	GY (kg ha^{-1})	DBIOM (kgha^{-1})	PH (cm)	EH (cm)	HI (%)
2015	Sole Maize (CN)	1453^{a}	7409^{a}	156^{a}	79^{a}	22^{a}
	Sole Maize (CA)	1444^{a}	6854^{a}	153^{a}	72^{a}	24^{a}
	Double Cropping (M then B) CA	1337^{ab}	7118^{a}	159^{a}	80^{a}	21^{a}
	Relay (M+B) + (B) under CA	972^{b}	5980^{a}	148^{a}	71^{a}	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}	52^{a}
	Sole Maize (CA)	3557^{a}	8363^{b}	153^{a}	78^{a}	47^{ab}
	Double Cropping (M then B) CA	3677^{a}	16050^{a}	128^{b}	52^{b}	27^{b}
	Relay (M+B) + (B) under CA	2626^{b}	5568^{b}	152^{a}	65^{ab}	54^{a}
	CV (%)	12.2	30.0	7.4	12.1	26.0
	F-test	*	*	*	*	ns
Combined (2015 and 2016)	Sole Maize (CN)	2834^{a}	8366^{b}	162a	78^{a}	37^{a}
	Sole Maize (CA)	2500^{a}	7608^{b}	153ab	75^{ab}	35^{a}
	Double Cropping (M then B) CA	2507^{a}	11584^{a}	144^{b}	66^{b}	24^{b}
	Relay (M+B) + (B) under CA	1799^{b}	5774^{b}	150^{ab}	68^{ab}	36^{a}
	CV (%)	16.4	28.8	8.2	11.4	25.2
	Treatment (F-test)	**	**	ns	ns	*
	Season (F-test)	***	**	ns	*	***
	Season*treatment (F-test)	ns	*	*	*	*

Where GY=Grain yield kg/ha, BIOM=Bio Mass kg/ha, PH=Plant height (cm), PH=Plant height (cm), EH= Ear Height (cm) and HI =Harvest index (%)

Table 2. Comparison of treatments for common bean yield (kg ha^{-1}) and other traits tested in 2015 and 2016.

Testing year and planting round	Treatments	GY	Biom	PPP	SPP	TSW	HI (%)
First round planting in 2015	Double Cropping (B then M) - CA	2618^{a}	4427	25	6	240	77
	Relay (M+B) + (B) - CA	1263^{b}	1507	21	5	234	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 (B then M) - CA	3149^{a}	4899^{a}	19^{a}	5	320	62
	Relay (M+B) +(B) - CA	1729^{b}	4466^{a}	20^{a}	5	230	31
	Lablab then (M +B) - 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 (M then B) - CA	2107^{a}	4338	15	5	262	48
	Relay (M+B) + (B) - CA	1353^{b}	3237	20	5	244	39
	Lablab then (M +B) - 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

Where GY=Grain yield kg/ha, BIOM=Bio Mass kg/ha, PPP=Number of pods per plant, SPP=Number of seeds per pod and HI =Harvest index in %.

While considering the productivity of the cropping systems from the first and second round planting in 2016, the highest bean grain yield was from double cropping (bean then maize) which averaged 3149 kg ha^{-1} 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^{-1}) from first planting also had 1729 kg ha^{-1}of bean from the first round and 1353 kg ha^{-1} from second round planting, and its total was 3081 kg^{-1} (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 from relay-intercrop and double-crop system for radish while relay-intercropping had greater yields for hairy vetch and faba bean. Similarly, based on field observation during the season, rather than planting lablab followed by maize-inter cropping, it is better planting maize-bean intercropping then lablab crop within the same season. Considering only bean biomass collected from the first and second round planting in 2016, lablab followed by maize-bean intercropping (lablab then maize + bean) had the highest biomass yield averaging 9414 kg ha^{-1} and followed by relay cropping (maize + bean + bean) which had 7703 kg ha^{-1} (Table 3). For maize, since maize crop was not successful during second planting, the biomass yield is computed only for data collected from first round planting (Table 3).

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.

	Grain yield (kgha^{-1})							
Cropping system	**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 (B then M) under CA	2618	-	3149	-	-	-	3149	-
Double Cropping (M then B) under CA	-	1337	-	3677	2107	-	2107	3677
Relay (M+B) + (B) under CA	1263	972	1729	2626	1353	-	3081	2626
Lablab then (M +B) under CA	-	-	-	-	2038	-	2038	-
Cropping system	**Biomass (kgha^{-1})**							
	Bean	**Maize**	**Bean**	**Maize**	**Bean**	**Maize**	**Bean**	**Maize**
Sole Maize (CN)	-	7409	-	9324	-	-	-	9324
Sole Maize (CA)	-	6854	-	8363	-	-	-	8363
Double Cropping (B then M) under CA	4427	-	4899	-	-	-	4899	-
Double Cropping (M then B) under CA	-	7118	-	16050	4338	-	4338	16050
Relay (M+B) + (B) under CA	1507	5980	4466	5568	3237	-	7703	5568
Lablab then (M +B) under CA	-	-	5410	-	4004	-	9414	-

Based on the equivalent conversion of bean yield into maize grain yield and sum of value with maize grain yield obtained from directly from the same treatments, the maximum maize grain yield (10021 kg ha^{-1}) was from relay cropping in 2016 compared with the other cropping systems. This is consistent with results by Paudel et al. (2001) who reported that relay cropping of finger millet (*Elusianacoracana* L.) under maize in mid hills of Nepal is the most important inter cropping from different forms of multiple cropping in order to increase of production in limited area and short span of time. The second-high yielding cropping system was double cropping (maize then bean) with 8735 kg ha^{-1}. Considering the systems with other crops from in the other study, Chavan et al. (2018) reported the highest system productivity in terms of rice equivalent grain yield (REGY) 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 (maize then bean) had the highest value (20388kg ha^{-1}) and followed by relay cropping (13271 kg ha^{-1}) (Fig. 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. He also reported higher biomass production performance (22-36%) by this cropping system compared with other cropping systems.

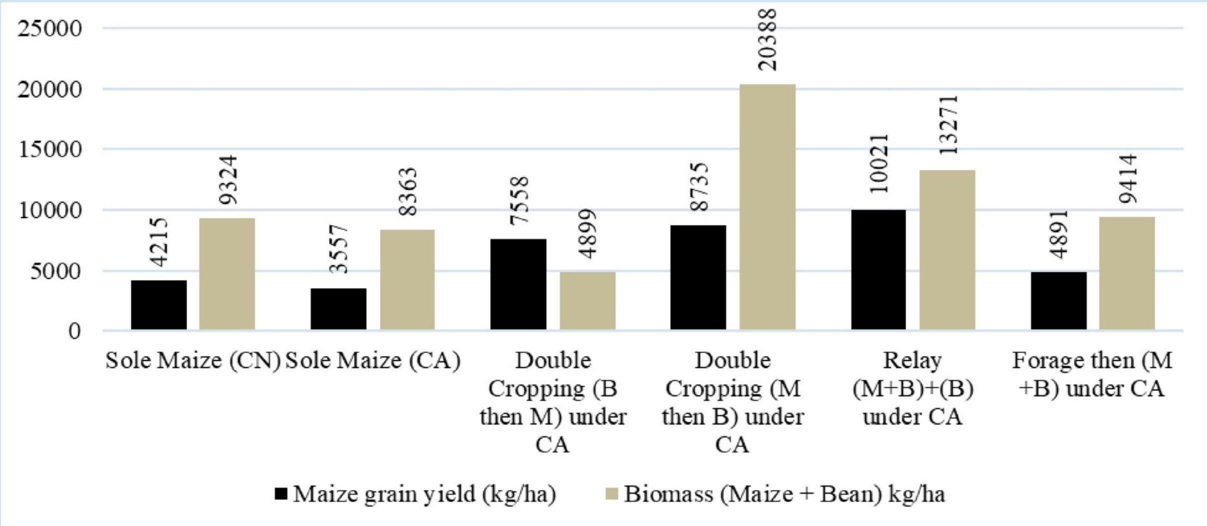

Figure 2. Maize grain (considering bean grain yield equivalent conversion into maize yield for plot which had common bean yield data) and total Biomass yield from the plot (maize and bean biomass added together) the result obtained from first and second round planning added in 2016.

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 (bean the maize) 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 cropping systems. Double cropping (maize then bean) had 316% biomass production efficiency than double cropping (bean the maize). The production efficiency of biomass from relay cropping was also 35% higher in the four cropping systems than maize followed by bean cropping systems.

Table4. 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.

	Grain yield		
Cropping system	**Relay (M+B) +(B) under CA**	**Double Cropping (M then B) under CA**	**Double Cropping (B then M) under CA**
Sole Maize (CN)	138	107	79
Sole Maize (CA)	182	146	113
Double Cropping (B then M) under CA	33	16	-
Double Cropping (M then B) under CA	15	-	-14
Relay (M+B) +(B) under CA	-	-13	-25
Lablab then (M +B) under CA	105	79	55

	Biomass yield	
Cropping system	**Double Cropping (M then B) under CA**	**Relay (M+B) +(B) under CA**
Sole Maize (CN)	119	42
Sole Maize (CA)	144	59
Double Cropping (B then M) under CA	316	171
Double Cropping (M then B) under CA	-	-35
Relay (M+B) +(B) under CA	54	-
Lablab then (M +B) under CA	117	41

The variance between cropping systems was significant for maize equivalent conversion of bean grain yields into maize plus value of maize grain yield in 2015 and 2016. For biomass, cropping systems had a significant effect on biomass production in 2016, but the effect was similar in 2015 (Table 5).

Table 5. Production efficiency of cropping systems for maize grain yield (kg ha^{-1}) 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 (B then M) - CA	6283^{a}	4427^{b}	7558^{b}	4899^{c}
Double Cropping (M then B) - CA	1337^{c}	7118^{ab}	8735^{b}	20388^{a}
Relay (M+B) + (B) - CA	4003^{b}	7487^{a}	10021^{a}	13271^{b}
Lablab then (M +B) - CA	-	-	4891^{c}	9414b^{c}
CV (%)	13.9	24.3	26.1	25.2
F-test	***	ns	***	***

3.2 Water Use Efficiency

The variance for water use efficiency showed significant differences between double cropping and relay cropping in 2015 and 2016 from first round planting of common bean. A similar trend was observed at second round planting. The water use efficiency for biomass production was not affected by treatments in 2015 and during both planting times in 2016. The sum of water use efficiency from first and second round planted common bean indicates the highest value from lablab followed by maize-bean inter-cropping with a value of 30 kg mm^{-1}, followed by relay cropping with 25 kg mm^{-1} for biomass. Regarding water use efficiency for grain yield, the highest was recorded from relay cropping (10 kg mm^{-1}) followed by double cropping (maize then bean) with 9 kg mm^{-1} (Table 6). These results indicate that relay cropping had a higher potential to convert the available soil moisture into grain yield.

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	
	Grain	Biom	Grain	Biom	Grain	Biom	Grain	Biom
Double Cropping (B then M) under CA	9a	15a	8a	12a	-	-	**8**	**12**
Double Cropping (M then B) under CA	-	-	-	-	9a	19a	**9**	**19**
Relay (M+B) + (B) Under CA	4b	5a	4b	11a	6b	14a	**10**	**25**
Lablab then (M +B) 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	-	-

For maize grain yield and biomass, water use efficiency was not influenced by cropping systems in 2015. To the contrary, the difference was significant for both maize grain and biomass in 2016 and across seasons. The cropping system x season interaction was significant for biomass, implying that the production of biomass in different cropping systems was season quality dependent (Table 7). Even season effect was highly significant for maize grain yield but cropping system x season was non-significant.

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 kgmm-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 (maize then bean).However, for biomass, the highest water use efficiency was obtained from double cropping (maize then bean) (29 kg mm-1) under CA and followed by sole maize under conventional practice (17 kgmm^{-1}). Across seasons, slightly higher water use efficiency was obtained from sole maize under conventional practice and followed by sole maize and double cropping (maize then bean) under CA for grain yield. 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). In contrast to the this experiment result Micheni et al.(2014) reported no significant difference in WUE for grain yield between the CA and conventional tillage systems across the four seasons but significantly lower efficiencies noted under farmers' practices in the upper midland agro-ecological zones(1200 meter above sea level) and lower midlands (900 meter above sea level) in Kenya.

Table 7. Water use efficiency ($kgmm^{-1}$) by cropping systems of maize kg mm^{-1} of rainfall for grain yield and biomass production in 2015 and 2016 cropping season.

Treatments	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 (M then B) CA	3^{ab}	17^{a}	7^{a}	29^{a}	5^{a}	23^{a}
Relay (M+B) + (B)-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
Treatment (F-test)	ns	ns	*	*	**	*
Season (F-test)	-	-	-	-	***	ns
Treatment*season (F-test)	-		-	-	Ns	*

Results of water use efficiency based on maize yield equivalents of beans and the maize yield from each treatment are summarized in Table 8. In 2015, cropping systems had a significant effect on grain yield and the highest water use efficiency was 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 Belg (short-rains) and water productivity than Kiremt sown continuous 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. Regarding biomass, the highest water use efficiency was 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, 1976; Siddoway and Barnett, 1977). The least WUE of biomass was obtained from double cropping (bean then maize) (9 kg mm^{-1}). Double cropping (maize then bean) had higher WUE than sole maize under conventional, sole maize (CA), Double Cropping (B then M) under CA, Relay (M + B) + (B) Under CA and Lablab then (M + B) 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 (B then M) under CA, and Lablab then (M + B) under CA (34, 49, 120 and 33%), respectively.

Table 8. Water use efficiency (kg mm^{-1}) by cropping systems maize grain yield considering equivalent bean conversion into maize for production efficiency and biomass production (sum of maize bean biomass) in 2015 and 2016.

Cropping system	2015		2016	
	Grain yield	Biomass	Grain yield	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 (B then M) under CA	15^{a}	11^{b}	13^{a}	9^{c}
Double Cropping (M then B) under CA	3^{c}	17^{ab}	13^{a}	31^{a}
Relay (M+B) + (B) under CA	10^{b}	18^{a}	14^{a}	19^{b}
Lablab then (M +B) under CA	-	-	8^{b}	14^{bc}
CV (%)	13.9	24.3	26.1	25.2
F-test	***	ns	***	***

4. Conclusion

The overall assessment of cropping systems under CA and CN indicating that, relay cropping had the highest maize grain yield considering bean equivalent to maize grain yield with addition of maize grain yield harvested from the plot directly. For biomass production (sum of the value of maize and bean) and double cropping (maize then bean) were the best cropping strategies under the Central Rift Valley conditions in Ethiopia. The higher grain and biomass yield, water use efficiency obtained from relay cropping and double cropping indicating the use of double cropping with diverse crops is good chose rather than the use of sole cropping. Double cropping systems utilized rainwater more efficiently than mono-cropping practices. Applying double cropping (maize then bean), 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 benefit from residual soil water and also reduce production risk during cropping seasons. From the cropping systems, rather than planting lablab crop at first time before maize-bean inter cropping, it is better to plant maize and bean intercrop at first round and then lablab crop at second round planting.

Acknowledgement

This research was funded by ACIAR (Australian Centre for International Agricultural Research) through Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) project. We thank Mrs. Maedin Tadesse, Mr. Zerihun Beshir, and Mr. Temesgen Gizaw for their assistance in data collection.

5. Reference

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

Baker, E. F. I., and Norman, D. W.1975. “Cropping Systems in Northern Nigeria,” In: Proceedings of the Cropping Systems workshop, IRRI, Los Banes, Philippines, pp. 334-361.

Baldy, C.1963. “Cultures associeeset Productivity del’Eau,” Ann. Agronomiques 14:489.

Chavan, A.P., N.G. Sonone, M.S. Jadhav and V.V. Sagvekar.2018. Identification of Profitable Rice Based Cropping System for South Konkan Coastal Zone. International Journal of *Current Microbiology and Applied Sciences ISSN: 2319-7706 Volume 7 Number 10 (2018). Journal homepage: http://www.ijcmas.com*

Dai, A. 2013. Increasing drought under global warming in observations and models. Nature Clim. Change 3, 52–58.

David, J.S., K. Dawit and A. Dawit, 2011. Seed, fertilizer, and agricultural extension in Ethiopia, Ethiopia Strategy Support Program II. IPPRI.

Debaeke, P., S. Pellerin S. and E. Scopel. 2017. Climate-smart cropping systems for temperate and tropical agriculture: mitigation, adaptation and trade-offs. Cah. Agric., 26, 34002.

EEA (Ethiopian Economic Association), 2012. Annual report on Ethiopian economy. Addis Ababa, Ethiopia.

Gliessman, S. R., and Amador, M. A.1979. “Ecological Aspects of Production in Traditional Agroecosystems in the Humid Lowland Tropics of Mexico,” Proceedings, Fifth InternationalSymposium for Tropical Ecology, Kuala Lumpur, Malaysia. April.

Gomez, K. A. and A. A Gomez. 1984. *Statistical procedures for agricultural research*. New York: Wiley-Inter science publication.

Greenland, D. J., and Lal, R. 1977. Soil Conservation and Management in the Humid Tropics (New York, NY: Wiley (ISBN 0-471-99473-1).

Karim, M., Y. Fracheboud, P. Stamp, 2000. Effect of high temperature on seedling growth and photosynthesis of tropical maize genotypes. J. Agron. Crop Sci. 184, 217-223.

Kassam, A. H., and Stockinger, K. R., "Growth and Nitrogen Uptake of Sorghum and Millet in Mixed Cropping," *S a m a r u Agrjc. IVew'sletter15:28, 1973.*

Lupi, A. and K. Kibert. 2019. Analysis of main growing Seasonal (Kirmet or Genna) rainfall and dry spell occurrence in semi-arid central rift valley of Oromia regional state, Ethiopia. J HortiSciand Crop Res 1(1): 101.

Malezieux, E., Y. Crozat, C. Dupraz, M. Laurans, D. Makowski, H. Ozier-Lafontaine, B. Rapidel, S. de Tourdonnet, M. Valantin-Morison.2007. Mixing plant species in cropping systems: concepts, tools and models. A review. Agron. Sustain. 43–62.

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

Micheni, A.N, F. Kanampiu, O. Kitonyo, D. M. mburu, E.N. Mugai, D. Makumbi *and* M. Kassie.2014. on-farm experimentation on conservation agriculture in maize-legume based cropping systems in kenya: water use efficiency and economic impacts. *Expl* Agric.: page 1 of 18 C Cambridge University Press 2015.

Mina N.P. 2016. Multiple Cropping for Raising Productivity and Farm Income of Small Farmers. Journal of Nepal Agricultural Research Council. ISSN: 2392-4535, Vol. 2:37-45, December 2016.

Musa, H. A. 2014. Farmer's decision to practice crop rotation in Arsi-Negele, Ethiopia: What are the determinants? International Journal of Sustainable Agricultural Research, 1(1): 19-27.

Paudel, M N. 2001. Findings of participatory rural appraisal survey conducted in the high hills of Dhankuta, Dolkha, Myagdi and Dailekh districts during 1999/2000 (2056/57). ARSP Working paper No 255, ISSN 1021-5034.

Rana, S.S and M. C. Rana. 2011. Cropping System. Department of Agronomy, College of Agriculture, CSK Himachal Pradesh KrishiVishvavidyalaya, Palampur, 80pp.

Samant, T.K.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.ISSN:0975-3710&E-ISSN: Volume7, Issue 11, 0975-9107.

Sanchez, P. A. 1976. Properties and Management of Soils in the Tropics (Wiley, NY: (ISBN 0-471-75200-2), IID. 478-532.

Sandler, L. & K. A. Nelson.2016. Inter- and Double-crop Yield Response to Alternative Crop Planting Dates. www.todayscience.org/as **Agricultural Science** Vol. 4, Issue 2.

Sankaranarayanan, P.Nalayini and C.S.Praharaj. 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.

Siddoway, F, H., and Barnett, A. P.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 JemalHassen. 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.

Stephen, R. G. Chapter V. Multiple Cropping Systems: A Basis for Developing anAlternative Agriculture. Environmental Studies. University of California. Santa Cruz California 95064.

Wilken, G, C.1974. "Some Aspects of Resource Management by Traditional Farmers," In: Biggs, H. H., and Tinnermeier, R, L. (eds.), Small Farm Agricultural Development Problems, ch. 111.

Zinke, P. 1962. "The Pattern of Influence of Individual Forest Trees on Soil Properties," Ecology 43:130.