Effect of Integrated Climate Change Resilient Cultural Practices on Productivity of Faba Bean (*Vicia faba* L.) under Rain-fed Conditions in Hararghe Highlands, Ethiopia

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Abstract: Alternative sustainable agriculture under the pressing impacts of climate variability on crop production is a primary concern in the Ethiopian development agenda towards sustained food security. Use of integrated crop management through climate resilient cultural practices that target diversity of produce, yield stability, losses due to pests, and reduction in economic and environmental risks is an appropriate strategy for sustainability of agricultural production. Field studies were conducted in Hararghe highlands, specifically at Haramaya during the 2012 and 2013 and at Arbarakate in the 2013 main cropping seasons to assess effects of integrated climate change resilient cultural practices on faba bean productivity. Three on-farm-based climate change resilient cultural practices: intercropping, compost application and furrow planting alone and in integration with the other practices were evaluated using Dagaga and Bulga-70 faba bean varieties and Melkassa-IV maize variety. The results showed that furrow planting with compost application in row intercropping increased soil moisture by up to 3.23% and cooled the soil temperature by up to 1.06^{o}C compared to sole cropping at Haramaya in 2013. Furrow planting with application of compost led to production of the highest (3.47 t ha^{-1} in 2012 and 4.25 t ha^{-1} in 2013) faba bean grain yields at Haramaya. The same treatment at Arbarakate produced the maximum (5.29 t ha^{-1}) faba bean grain yield in 2013. This was closely followed by the yield obtained in response to the application of compost at both locations in 2013 and by the yield obtained in response to furrow and sole cropping at Haramaya in 2012. Compost fertilization with or without furrow planting led to the production of consistently heavier grains. The total Land Equivalent Ratio (1.01 to 1.76) indicated a higher grain yield advantages of faba bean-maize intercropping over sole faba bean cropping at both locations over the two years. The overall results demonstrated that integrated climate resilient cultural practices significantly increased productivity of the crop as a result of enhancing contents of soil nutrients, soil moisture, soil organic carbon, and regulating soil and canopy temperatures as well as through buffering the root environment.

Keywords: Compost; Furrow planting; Grain yield; Land Equivalent Ratio; Row intercropping; Soil moisture and temperature; Sole cropping

1. Introduction

Faba bean (*Vicia faba* L.) is a cool-season crop and is grown worldwide as a grain and green-manure legume. The crop is used for both human consumption and animal feed as a source of protein and carbohydrate (Salmeron *et al*., 2010). It is a common breakfast food in many regions and countries, including Ethiopia (Singh and Bhatt, 2012). Faba bean is also used as an excellent component of crop rotations - capable of fixing atmospheric nitrogen; and is used as green manure to reduce the use of nitrogen fertilizers due to environmental concerns (Salmeron *et al*., 2010; Singh and Bhatt, 2012). Moreover, it is useful in the sustainability of cropping systems via crop diversification, leading to decreased disease, pest and weed build-up (Jensen *et al*., 2010).

Globally, China is the largest producer of faba bean, followed by Egypt, Ethiopia and France (Salmeron *et al*., 2010). In Africa, Egypt, Ethiopia, Sudan and Morocco are the leading producers of the crop (Akibode and Maredia, 2011). In Ethiopia, faba bean production is estimated to account for 3.94% of the total grain production (CSA, 2014). However, the average yield of faba bean under smallholder farmers ranges from 1.0 to 1.2 t ha^{-1}, which is five times lower than the faba bean production in Central Europe and some sub-Saharan African countries (Agegnehu *et al*., 2006). Faba bean production fluctuates and the world's cultivated area of faba bean decreased in the last 50 years (Rosegrant, 2010) though it has high production potential. Climate variability, diseases, weeds, and other pests are the major factors constraining faba bean production. Faba bean is regarded as a drought-sensitive crop (Grashoff, 1990) and the major factor restricting faba bean cultivation is the high year-to-year yield variability usually due to drought or moisture stress (Karamanos and Gimenez, 1991).

Climate is one of the main determinants of agricultural crop production (Knox *et al*., 2011; Turner, 2011). Agriculture is often regarded as one of the sectors most

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ISSN 1992-0407

vulnerable to climate change in the developing world. Similarly, agriculture in Ethiopia is heavily dependent on rain-fed production where its geographical location and topography, plus a low adaptive capacity, make the country highly vulnerable to the adverse impacts of climate change. Agriculture constitutes 40% of the country's GDP, on which 80% of the people rely for their livelihoods (FDRE-EPA, 2011). Currently, 30 developing nations face water shortages and by 2050, this could increase to 50 nations mostly in the developing countries (Dixon, 2009). Water scarcity and the degradation of arable crop land are the most serious obstacles inhibiting future increases in food production (Dixon, 2009).

Climate change has the potential to exacerbate the stresses on crop plants, potentially leading to catastrophic yield reductions to both irrigated and non-irrigated crops. This phenomenon could be manifested through increased moisture stress and drought in which crop production declines and entire harvests can be lost, greatly impacting seed viability, and plant growth, development, stature, phenology, fruiting, seed mass, seed quality, fiber quality, and the qualities of beverage crops, fruits, and aromatic and medicinal plants (Masters *et al*., 2010). Simultaneously, climate change will alter phasing of plant life-cycle stages and their rates of development for pests and pathogens and associated antagonistic organisms (Chakraborty, 2011). Thus, on one hand, the level of crop losses will increase while the efficacy of control measures could fall when faced with greater populations of pests and pathogens (Coakley *et al*., 1999).

Increase in the projected world population [in the case of Ethiopia, estimated to be 130 million by 2030, (FDRE-EPA, 2011)] and consequent human needs for food, cause additional pressure on the limited natural resources and the sustainability of agriculture. However, land is a primary resource that cannot be created. There is, therefore, a finite amount beyond which the cropped area cannot be increased. About 40% of the world's arable land is now degraded to some extent and most of that land is in the least developed nations in densely populated, rain-fed farming areas, where overgrazing, deforestation and inappropriate land use compound the problems (Dixon, 2012). In Ethiopia, food production on a continually shrinking farm size is also a prime developmental challenge for a rapidly ever growing population.

Considering all the uncertainties, it will be very important to develop effective mitigating or adaptive crop management strategies that minimize the risk of severe crop losses under the future climatic conditions, primarily focusing on improved management and use of the limited natural resource bases. The strategies may include shifts in crops and varieties adapted to future climate, shifts in crop diversification resistant or tolerant to insect pests and diseases (Fadda, 2011) and biodiversity restoration (Li, 2011). Diversification of agricultural systems can also significantly reduce the vulnerability of production systems to greater climate variability and extreme events, thus protecting vulnerable rural farmers and agricultural production (Li, 2011). Moreover, integrated nutrient management (Katungi *et al*., 2009), and conservation agriculture and efficient moisture conservation (Heluf, 2003) practices are also included under risk aversion from the impacts of climate variability and extreme weather events on subsistence agriculture and farmers.

Integrating on-farm-based climate change resilient cultural practices for production and management of crop diseases has a dual role for understanding effects of climate change and the role of these practices for mitigation or adaptation. However, research on field plot-based empirical climate change effects is practically a challenge but could be approached through climate change resilient cultural practices. These practices enhance the capacity of an ecological system to absorb stresses while retaining its organizational structure and productivity, the capacity for self-organization, and the ability to adapt to stress and change following a perturbation (Cabell and Oelofse, 2012). Thus, a "resilient" agroecosystem would be capable of providing food production, even when challenged by severe drought or by erratic rain-fall (Heal, 2000).

To this effect, productivity of faba bean needs to be assessed and characterized under integrated climate change resilient cultural practices. Nonetheless, field-based data on effects of climate variability and crop productivity in Ethiopia is limited. The consequences of new cropping systems designed to mitigate or adapt to climate change should be studied. Since food legumes used by farmers will be key components of many cropping systems and management options, such cropping systems and management options should be revisited based on the current changing environments (Ahmed *et al*., 2011). Thus, the potential of integrated climate resilient cultural practices to sustainably maintain crop production in the face of current and future climate change scenarios has to be elucidated. Therefore, the objective of this study was to assess the effect of integrated climate resilient cultural practices on faba bean productivity under rain-fed conditions in Hararghe highlands of Ethiopia.

2. Materials and Methods

2.1. Experimental Sites

Field experiments were conducted at two locations under rain-fed conditions in the 2012 and 2013 main cropping seasons. The 2012 main cropping season field experiment was conducted on a sandy clay loam soil (Gelgelo, 2012) on the main campus of Haramaya University at the experimental field station. The station is located at 9°26'N and 42°3'E with an altitude of 2006 m.a.s.l. The mean annual rain-fall for the location is 790 mm with mean minimum and maximum temperatures of 14 and 23.4 °C, respectively. The 2013 field experiment was conducted at Haramaya University on the same soil and on a clay vertisol at Arbarakate Farmers' Training Center (FTC) during the main cropping season. Arbarakate FTC is located at 9°2.86'N and 40°54.79'E with an altitude of 2274 m.a.s.l. in West Hararghe Zone at a distance of about 180 km to the west of Haramaya. Arbarakate is characterized by extended higher precipitation (estimated to exceed 1300 mm per annum) and many rainy days during the cropping periods with mean daily temperatures ranging between 13.14 and 17.52 °C. The soil of the experimental site at Haramaya had organic matter content of 1.0%, total nitrogen content of 0.17%, available phosphorus content of 8.72 mg kg^{-1} and pH of 8.13 (Gelgelo, 2012). Some of selected soil properties at Arbarakate included organic matter (3.49%), organic carbon (2.03%), total nitrogen (0.17%), available phosphorus (38.24 mg kg^{-1}) and pH (5.66) (own analysis).

2.2. Weather Data at Experimental Sites during the Cropping Seasons

Monthly total rainfall in mm, daily maximum and minimum temperatures in °C were obtained for Haramaya University experimental site of the cropping periods of the seasons from its own meteorological station. The weather data obtained from the nearby stations for Arbarakate were found unrepresentative and consequently not included here. However, the weather trend at Arbarakate was characterized by many rainy days, extended period of rainfall and the daily minimum and maximum temperatures were derived using the Adiabatic Lapse Rate Model (Brunt, 2007) from the nearby meteorological station. Also the monthly total rain-fall and the monthly average temperature in the cropping seasons are presented in Table 1.

Table 1. Monthly mean temperature (°C) and monthly total rainfall (mm) during faba bean growing periods at Haramaya and Arbarakate, Ethiopia, in 2012 and 2013 main cropping seasons.

Cropping month	Mean of temperature (°C)			Monthly rain-fall (mm)	
	Haramaya		Arbarakate	Haramaya	
	2012	2013	2013	2012	2013
June	19.97	19.30	17.52	0.00	15.80
July	18.56	17.63	15.81	214.00	215.40
August	18.90	18.25	16.48	149.50	185.10
September	18.73	18.43	16.62	105.00	142.10
October	15.50	16.82	15.47	4.60	71.60
November	14.68	15.04	13.14	0.50	81.70
Mean	17.72	17.58	15.84	78.93	118.62

2.3. Experimental Materials

2.3.1. Planting material

The two faba bean varieties used in this study were Degaga (moderately resistant to major faba bean diseases) and Bulga-70 (moderately susceptible) and their characteristic features are presented in Table 2. Both faba bean varieties were obtained from Holleta Agricultural Research Center, Ethiopia. The maize variety used as a component crop was Melkassa-IV (*ECA-EE-36*), which was obtained from Melkassa Agricultural Research Center, Ethiopia. Melkassa-IV was released in 2006 with an agronomic attribute: area of adaptation (altitude of 1000-1600 meters above sea level, rainfall of 500-700 mm annual rainfall), early maturing (105 days) and a production potential of 2-4 t ha^{-1}.

Table 2. Characteristic features of faba bean varieties used for the field experiment at Haramaya and Arbarakate, Ethiopia, during the 2012 and 2013 main cropping seasons.

Faba bean variety	Year of release	Area of adaptation		Maturity (days)	Seed size (g)	Yield (t/ha)	
		Altitude (m)	Annual rainfall (mm)			On station	On farm
Degaga	2002	1800-3000	800-1100	116-135	400-450	2.5-5.0	2.0-4.5
Bulga-70	1994	2300-3000	800-1100	143-150	400-450	2.0-4.5	1.5-3.5

2.3.2. Fertilizer Material

The compost used in this study to substitute the application of mineral fertilizer was mainly made of a pile of khat (*Catha edulis* Forsk) residues collected from the nearby market of Awaday, eastern Ethiopia. Well-decomposed and matured compost was air-dried and sieved. Composite random samples were taken for chemical analysis before application. The compost constituted organic carbon (8.01%), organic matter (13.80%), total nitrogen (0.69%), available phosphorus (234.80 mg kg^{-1}) and C:N ratio of 11.61. In the experiment, the compost was row applied to a depth of 10-15 cm at the rate of 8 t ha^{-1} and mixed with the soil a week before maize planting and four weeks in 2012 and three weeks in 2013 before faba bean planting. Furrows were prepared by digging about 20 cm deep rows once the faba bean was planted and established as seedling, and rain water was made to stagnate.

2.4. Treatments and Experimental Design

Three on-farm based climate resilient cultural practices (crop diversification in the form of intercropping, moisture conservation as planting in furrows and soil nutrient management as compost application), two faba bean varieties and one open pollinated Melkassa-IV maize variety were used in this study. Thus, the treatments included faba bean-maize row intercropping, furrow planting, compost application and sole faba bean row planting, and sole maize row planting. The treatments were applied solely and in integration with each other (Table 3). A total of 17 treatments (for both faba bean varieties) were laid out in a randomized complete block design in a factorial arrangement with three replications. In a gross plot size of 4 m x 3.2 m, a 1 maize: 1 faba bean planting pattern of row intercropping was maintained by planting maize rows spaced 0.80 m apart and planting one row of faba bean between the two maize rows. In the row intercropping, 5 rows of maize were intercropped with 4 rows of faba bean variety each at the center of the two maize rows per plot. In addition, sole maize and sole faba bean row planting were included as experimental treatments, which were planted at 0.80 m x 0.40 m and 0.40 m x 0.10 m inter-row and intra-row spacing, respectively. In case of sole faba bean row planting there were 10 rows per plot. In the intercrops, maize was planted three weeks in 2012 and two weeks in 2013 prior to faba bean planting. The spacing between blocks was 1.5 meter and that between plots was 1 meter.

Table 3. Treatment combinations and their respective descriptions used for faba bean and maize field experiments at Haramaya during the 2012 and 2013 and at Arbarakate in the 2013 main cropping seasons.

S.No.	Treatment	Treatment combination description
1	SP	Sole faba bean row planting (control)
2	FP	Furrow faba bean planting
3	CA	Faba bean planting using compost application (compost fertilization)
4	RI	Faba bean-maize row intercropping
5	FP + CA	Faba bean furrow planting with compost application
6	FP + RI	Faba bean furrow planting in faba bean-maize row intercropping
7	CA + RI	Faba bean planting using compost application in faba bean-maize row intercropping
8	FP + CA + RI	Faba bean furrow planting with compost application in faba bean-maize row intercropping
9	SMA	Sole maize row planting

2.5 Experimental Procedure

Sowing of maize was done manually by planting two seeds per hill, which were later thinned to one plant per hill. The faba bean varieties were also manually planted. Maize was planted at Haramaya on 21 June 2012 and on 27 June 2013; and at Arbarakate on 3 July 2013. Faba bean was planted at Haramaya on 11 July 2012 and on 12 July 2013; and at Arbarakate on 16 July 2013. The crops were grown without application of any chemical fertilizer. Weeding and other agronomic practices were done properly and uniformly as per the recommendations to grow a successful crop.

2.6. Data Collection and Measurement

2.6.1. Soil Moisture and Soil Temperature Assessment

In the 2013 cropping season at Haramaya, weekly soil moisture (%) and temperature (^{o}C) from the most integrated climate resilient cultural practices (furrow planting with compost fertilization in row intercropping) treated and sole cropped plots of faba bean were recorded. Soil moisture was determined by gravimetric measurement. In the gravimetric method, measurement of soil moisture was made on soil samples of known weight or volume. Soil samples for moisture content were taken from 40 cm depths collected with soil auger starting from the fourth week of July. They were collected in air-tight aluminum containers. The fresh soil samples were weighed and dried in an oven at 105 ^{o}C for about 24 hours until all the moisture was driven off. After removing from oven, they were cooled slowly to room temperature and weighed again. The difference in weight was considered as the amount of moisture in the soil. The soil's moisture content was expressed as a fraction and as percentage on a gravimetric basis using a established formula of Lal and Shukla (2004):

Gravimetric water (%) = [(Wet weight-Dry weight)/Dry weight] x 100 (1)

The soil temperature was recorded by using soil thermometer. At the middle of each sole cropped and highly integrated climate change resilient cultural practice treated rows of plots, thermometers were inserted to the depth of 20 cm for about 5 minutes at 7:00 to 9:00 AM and 3:00 to 6:00 PM twice a week to measure diurnal soil temperatures. The weekly average for each temperature per plot was calculated.

2.6.2. Assessment of crop growth and yield parameters

Data on faba bean growth and yield parameters were recorded from each plot. The growth parameter included plant height (cm). Plant height was determined by measuring the mean height of ten randomly taken plants from the ground level to the apex of the matured plant. The yield parameters included number of pods per plant (NPPP), number of seeds per pod (NSPP), hundred seed weight (HSW) and grain yield. Grain yield (t ha^{-1}) was determined by estimating the total seed mass after threshing at harvest from the respective harvestable areas of each plot. Four middle rows were harvested for intercropped and eight rows were harvested for sole-cropped faba bean plots.

The faba bean grain yield was adjusted to 10% moisture level by using the formula: Yield at % moisture = W*C.F., where W was unadjusted grain weight and C.F was a correction factor which was obtained after oven drying of 100 g unadjusted grain sample at 100 ^{o}C for 48 hours for complete drying. The C.F was determined using the table of Birru (1979) that gives a C.F. value for the corresponding dry weight of the 100 g sample. Percent moisture was taken after threshing pods using Draminski Grain Moisture Meter (Owocowa 17, 10-860 Olsztyn). NPPP were determined as the mean of ten randomly taken faba bean plants per plot and NSPP were also determined by taking the mean of seeds of ten randomly taken pods of plants per plot. HSW (g) was obtained by randomly counting and weighing 100 seeds per plot. Moreover, grain yield (t ha^{-1}) of maize was determined after shelling the dried cobs from each net plot area at harvest both from sole and intercropped plots. The maize grain yield was adjusted to 12.5% moisture level using the same formula used for faba bean. Percent moisture was taken using the same instrument as in faba bean grain yield.

The productivity of faba bean intercropping was evaluated using land equivalent ratio (LER) index (Mead and Willey, 1980), where LER is defined as:

$$LER = LA + LB = \frac{YA}{SA} + \frac{YB}{SB} \qquad (2)$$

where LA and LB are the LERs for the individual crops (faba bean and maize, respectively). YA and YB are the individual crop yields in intercropping, where SA and SB are their yields as sole crops. The partial LERs are then summed up to give the total LER for the intercrop. When LER > 1 there is an intercropping advantage in improved use of environment resources for plant growth; when LER = 1 there is no intercropping advantage/disadvantage, with respect to sole crop; when LER < 1 there is a disadvantage to intercropping and implying that the resources are used more efficiently by sole cropping rather than by intercropping. To remove faults relating LER, the maximum monocropping yield was used.

2.7. Data Analysis

Analysis of variance (ANOVA) was run for each growth and yield parameter of faba bean to determine treatment effects across locations in each year. ANOVA was also run for both soil moisture and temperature data to determine effects of integrated climate change resilient cultural practices and sole cropping systems at Haramaya in 2013. ANOVA was computed using the SAS GLM Procedure (SAS Institute, 2001) and treatment mean separations were made using least significant difference (LSD) at 0.05 probability level. The two locations and seasons were considered as different environments because of heterogeneity of variances as tested using Bartlett's test (Gomez and Gomez, 1984) and the F-test was significant for most of the parameters studied. Thus, data were not combined for analysis.

3. Results

3.1. Soil Moisture

The soil moisture content was significantly ($P \leq 0.05$) influenced by intercropping integrated climate resilient cultural practices and sole cropping systems in most of the cropping months in both faba bean varieties at Haramaya in 2013 (Table 4). Higher soil moisture content was recorded in plots treated with the most integrated combination of climate resilient cultural practices over sole faba bean treatment in all cropping months. Soil moisture test data also revealed that moisture content consistently decreased during the cropping months where the lowest value was obtained in October for both faba bean varieties. The most integrated cropping system numerically increased soil moisture by 1.24 to 3.23% for Degaga and by 1.73 to 2.26% for Bulga-70 variety compared to sole cropped systems.

Table 4. Effect of climate change resilient cultural practices on monthly average soil temperature and soil moisture at Haramaya, Ethiopia, during the 2013 main cropping season.

Treatment [1]		Cropping months of faba bean							
		July		August		September		October	
Cultural practice	Variety	Soil temp. (°C)	Soil moisture (%)	Soil temp. (°C)	Soil moisture (%)	Soil temp. (°C)	Soil moisture (%)	Soil temp. (°C)	Soil moisture (%)
SP	Degaga	14.28[a]	13.36[a]	14.17[a]	10.43[a]	14.94[a]	8.45[a]	15.26[a]	7.39[a]
FP+CA+RI	Degaga	13.97[a]	14.60[a]	13.92[b]	12.96[b]	14.13[b]	10.76[b]	14.31[b]	10.62[b]
SP	Bulga-70	14.20[a]	13.01[a]	14.28[a]	10.95[a]	15.12[a]	9.69[a]	15.20[a]	8.93[a]
FP+CA+RI	Bulga-70	13.99[a]	14.74[a]	14.02[a]	13.21[b]	14.62[b]	11.88[b]	14.14[b]	10.72[b]
LSD (0.05)		0.18	1.45	0.16	0.61	0.19	1.00	0.24	0.81
CV (%)		0.92	7.35	0.78	3.66	0.92	6.96	1.15	6.15

Note:[1]*SP, sole planting; and FP + CA + RI, furrow planting with compost application in row intercropping. Means in each column followed by the same letter are not significantly different at 5% probability level.*

3.2. Soil Temperature

The monthly average soil temperature was also significantly ($P \leq 0.05$) influenced by intercropping integrated climate change resilient cultural practices and sole faba bean planting at Haramaya during most of the cropping months in 2013 (Table 4). However, the data depicted in the table clearly show that significant differences occurred for Bulga-70 only in September and October. Nonetheless, in all cases, the lower monthly average soil temperature was recorded for the most integrated climate change resilient cultural practices treated plots than for sole faba bean planting. Unlike soil moisture test data, soil temperature increased during the cropping months, with the highest being recorded in October. The most integrated treatment lowered and cooled soil temperature by 0.25 to 0.95 ^{o}C for Degaga and by 0.21 to 1.06 ^{o}C for Bulga-70. A similar trend was also observed for both monthly average minimum and maximum soil temperature data for the cropping months of both faba bean varieties (data not shown).

3.3. Plant Height

The data on faba bean plant height generally did not show significant variation among the climate resilient cultural practices used and as compared to the control treatment at Haramaya in 2012 and both at Haramaya and Arbarakate in 2013 (Tables 5 and 6). However, a significant ($P \leq 0.05$) difference in height was obtained between varieties at Arbarakate in 2013. Although not significant, intercropping and intercropping integrated with climate resilient cultural practice(s) treated plots (referring to furrow planting in row intercropping and/or compost application in row intercropping and/or furrow planting with compost application in row intercropping or intercropping integrated treatments hereafter) produced taller faba bean plants than sole faba bean planting at Haramaya in 2012 and both at Haramaya and Arbarakate in 2013 main cropping seasons. Taller Degaga faba bean plants were also recorded at Arbarakate than Bulga-70 during the 2013 cropping season.

3.4. Faba Bean Yield Components

Data on yield components are presented in Tables 5 and 6. Statistical analysis of the data showed that climate resilient cultural practices generally had significant ($P \leq 0.05$) effect on hundred seed weight of faba bean at Haramaya in 2012 and at both locations in 2013 main cropping seasons. However, a general non-significant trend on NPPP and NSPP of faba bean were observed at both locations and across the main cropping seasons. It was also observed that the variety Degaga had significantly heavier seed weights than the variety Bulga-70. Sole cropping treatments caused heavier faba bean seeds than their respective intercropping and intercropping integrated treatments at both locations and over seasons. Comparably, higher NPPP and 100-seed weights of faba bean were recorded at Haramaya and Arbarakate in 2013 than at Haramaya in 2012 main cropping season.

Heavier faba bean grains were obtained from plots where faba bean plants were planted with compost fertilization or planted in furrows with compost fertilization at both locations in 2013. In 2012, heavier faba bean grains were harvested from furrow planted or furrow planting with compost fertilized plots at Haramaya than from sole faba bean planting. However, lower 100-seed weights of faba bean were recorded in plots that were planted either in intercropping or intercropping integrated treated plots at both locations in 2013. The overall condition was a little bit different during 2012 as compared to 2013.

3.5. Grain Yield

The effects of climate resilient cultural practices and sole cropping on grain yield of faba bean are presented in Tables 5 and 6. There were significant ($P \leq 0.05$) differences in faba bean grain yield due to climate change resilient cultural practices at Haramaya in 2012 and at both Haramaya and Arbarakate during the 2013 cropping season. Significant differences were also found between Degaga and Bulga-70 at both locations in 2013 but not at Haramaya in 2012. Both faba bean varieties gave higher grain yield in the different treatments at both locations in 2013 than in the year 2012. The grain yield of faba bean obtained at Arbarakate was even higher than that of Haramaya. Thus, the faba bean overall mean grain yield was higher by 161.67% for Degaga and by 142.31% for Bulga-70 at Haramaya in 2013 than in 2012 main cropping season.

The highest grain yields were consistently obtained from non-intercropped (furrow planting and/or compost fertilization and/or furrow planting with compost application) and sole cropped plots at both locations and years. Among those treatments that produced higher faba bean grain yield at Haramaya, furrow planting with compost fertilization resulted in the highest (3.47 t ha^{-1} in 2012 and 4.25 t ha^{-1} in 2013) faba bean grain yield. Furrow planting with compost fertilization also produced the maximum (5.29 t ha^{-1}) faba bean grain yield at Arbarakate in 2013. It was followed by compost fertilization at both locations (4.14 t ha^{-1} at Haramaya and 4.99 t ha^{-1} at Arbarakate) in 2013. However, furrow and sole row planting resulted in production of the highest faba bean grain yields next to furrow planting with compost fertilization at Haramaya in 2012.

In both cropping seasons at Haramaya and Arbarakate, faba bean grain yields of each sole row planting were also greater than the grain yield of their respective intercrops. The lowest faba bean grain yield was recorded for either intercropped or intercropping integrated treated plots as compared to non-intercropped and sole cropped treatments. The grain yield obtained at Haramaya ranged from 0.96 to 1.22 t ha^{-1} (in 2012) and from 2.48 to 2.67 t ha^{-1}(in2013). The grain yield of faba bean at Arbarakate ranged from 2.99 to 3.29 t ha^{-1} in 2013. Among intercropping integrated treatments, compost fertilization in row intercropping treated plots gave the highest (2.67 t ha^{-1} at Haramaya and 3.29 t ha^{-1} at Arbarakate) faba bean grain yield in 2013. However, furrow planting with compost fertilization in row intercropping treated plots at Haramaya resulted in a higher (1.22 t ha^{-1}) faba bean grain yield than others in 2012.

Table 5. Effects of integrated climate change resilient cultural practices on growth and yield parameters of faba bean (*Vicia faba*) at Haramaya, Ethiopia, during the 2012 and 2013 main cropping seasons.

Treatment [1]	Haramaya[2]									
	2012					2013				
	Height (cm)	NPPP	NSPP	HSW (g)	Yield (t ha^{-1})	Height (cm)	NPPP	NSPP	HSW (g)	Yield(t ha^{-1})
Faba bean variety										
Degaga	1.59^{a}	12.59^{a}	2.86^{a}	55.02^{a}	2.27^{a}	1.68^{a}	17.99^{b}	3.03^{a}	60.09^{a}	3.67^{a}
Bulga-70	1.56^{a}	13.58^{a}	2.78^{b}	47.89^{b}	2.08^{a}	1.65^{a}	21.60^{a}	3.01^{a}	49.57^{b}	2.96^{b}
LSD (0.05)	0.03	1.72	0.08	1.05	0.35	0.04	1.74	0.08	1.02	0.18
Resilient cultural practice										
SP	1.55^{bc}	16.02^{a}	2.93^{a}	51.94^{abc}	3.36^{a}	1.65^{a}	19.93^{abcd}	3.10^{a}	54.99^{ab}	3.93^{a}
FP	1.55^{bc}	15.67^{a}	2.75^{bc}	53.73^{a}	3.18^{a}	1.64^{a}	18.17^{cd}	2.97^{a}	55.27^{ab}	3.90^{a}
CA	1.54^{c}	13.03^{abc}	2.90^{ab}	50.35^{c}	2.92^{a}	1.66^{a}	18.67^{bcd}	3.03^{a}	55.77^{ab}	4.14^{a}
RI	1.58^{abc}	11.58^{bc}	2.75^{bc}	50.40^{c}	1.10^{b}	1.68^{a}	21.58^{abc}	2.97^{a}	53.80^{b}	2.48^{b}
FP + CA	1.55^{bc}	14.80^{ab}	2.78^{abc}	52.74^{ab}	3.47^{a}	1.66^{a}	17.57^{d}	3.03^{a}	56.92^{a}	4.25^{a}
FP + RI	1.64^{a}	11.63^{bc}	2.73^{c}	51.06^{bc}	1.22^{b}	1.69^{a}	22.17^{a}	3.07^{a}	53.77^{b}	2.55^{b}
CA + RI	1.62^{ab}	10.22^{c}	2.90^{ab}	50.59^{c}	0.96^{b}	1.68^{a}	18.63^{bcd}	2.97^{a}	54.25^{b}	2.67^{b}
FP + CA + RI	1.59^{abc}	11.73^{bc}	2.80^{abc}	50.83^{bc}	1.22^{b}	1.68^{a}	21.67^{ab}	3.00^{a}	53.86^{b}	2.60^{b}
LSD (0.05)	0.07	3.45	0.15	2.11	0.71	0.08	3.48	0.17	2.04	0.37
CV (%)	3.55	22.33	4.65	3.48	27.51	3.94	14.89	4.68	3.15	9.39

Note: [1]SP, sole planting; FP, furrow planting; CA, compost application; RI, row intercropping; FP + CA, furrow planting with compost application; FP + RI, furrow planting in row intercropping; CA + RI, compost apllication in row intercropping; and FP + CA + RI, furrow planting with compost application in row intercropping.

[2] *NPPP, number of pods per plant; NSPP, number of seeds per pod; and HSW, hundred seed weight.*

Means in each column followed by the same letter are not significantly different at 5% probability level.

Table 6. Effects of integrated climate change resilient cultural practices on growth and yield parameters of faba bean (*Vicia faba*) at Arbarakate, Ethiopia, during the 2013 main cropping season.

Treatment [1]	Arbarakate[2]				
	Height (cm)	NPPP	NSPP	HSW (g)	Yield ($t\ ha^{-1}$)
Faba bean variety					
Degaga	1.67^{a}	20.30^{a}	3.03^{a}	60.10^{a}	4.26^{a}
Bulga-70	1.64^{b}	21.21^{a}	3.01^{a}	49.36^{b}	3.71^{b}
LSD (0.05)	0.03	1.34	0.08	0.82	0.19
Resilient cultural practice					
SP	1.63^{ab}	20.60^{ab}	3.03^{a}	54.59^{abc}	4.79^{b}
FP	1.62^{b}	19.20^{b}	3.03^{a}	55.06^{abc}	4.34^{c}
CA	1.64^{ab}	21.47^{ab}	3.00^{a}	56.08^{a}	4.99^{ab}
RI	1.68^{ab}	21.97^{a}	2.97^{a}	53.82^{c}	3.14^{d}
FP + CA	1.63^{b}	19.97^{ab}	3.03^{a}	55.72^{ab}	5.29^{a}
FP + RI	1.67^{ab}	20.33^{ab}	3.10^{a}	54.07^{c}	2.99^{d}
CA + RI	1.69^{a}	20.33^{ab}	3.00^{a}	54.23^{bc}	3.29^{d}
FP + CA + RI	1.67^{ab}	22.17^{a}	3.00^{a}	54.29^{bc}	3.05^{d}
LSD (0.05)	0.06	2.68	0.16	1.64	0.39
CV (%)	2.98	10.95	4.43	2.54	8.29

Note: [1]SP, sole planting; FP, furrow planting; CA, compost application; RI, row intercropping; FP + CA, furrow planting with compost application; FP + RI, furrow planting in row intercropping; CA + RI, compost apllication in row intercropping; and FP + CA + RI, furrow planting with compost application in row intercropping.
[2] *NPPP, number of pods per plant; NSPP, number of seeds per pod; and HSW, hundred seed weight.*
Means in each column followed by the same letter are not significantly different at 5% probability level.

3.6. Land Equivalent Ratio (LER)
Evaluation of intercropping advantage was performed on the basis of LER of intercropping index and, hence, the significance of higher faba bean grain yield gain from sole and non-intercropping planted plots could be explained using LER. The total LER values computed for faba bean at Haramaya in 2012 and at both locations in 2013 are presented in Table 7. The total LER values for intercropped plots were more than one at both locations and years. The values at Haramaya ranged from 1.02 to 1.16 in 2012 and 1.63 to 1.76 in 2013. Similarly, LER values ranged from 1.55 to 1.76 at Arbarakate in 2013. Maximum grain yield advantages of 16% were obtained at Haramaya in 2012 and 76% at both Haramaya and Arbarakate areas in 2013. The highest (1.76) LER value was obtained when faba bean was row intercropped with maize at both locations in 2013, indicating grain yield benefit from 1.76 hectares of sole faba bean crop could be obtained from one hectare of intercropped faba bean and could increase productivity by 76% over the sole planting of each crop.

Table 7. Effects of intercropping systems on grain yield ($t\ ha^{-1}$) and total land equivalent ratio (LER) of faba bean at Haramaya and Arbarakate, Ethiopia during the 2012 and 2013 main cropping seasons.

Treatment [1]	Haramaya						Arbarakate		
	2012			2013			2013		
	Grain yield ($t\ ha^{-1}$)		Total LER	Grain yield ($t\ ha^{-1}$)		Total LER	Grain yield ($t\ ha^{-1}$)		Total LER
	Faba bean	Maize		Faba bean	Maize		Faba bean	Maize	
SP	3.36	6.39		3.93	2.61		4.79	2.54	
RI	1.10	4.88	1.09	2.48	2.64	1.64	3.14	2.69	1.71
FP+RI	1.22	5.08	1.16	2.55	2.66	1.67	2.99	2.34	1.55
CA+RI	0.96	4.69	1.02	2.67	2.83	1.76	3.29	2.72	1.76
FP+CA+RI	1.22	4.89	1.13	2.60	2.54	1.63	3.05	2.48	1.61

Note: [1] SP, sole planting; RI, row intercropping; FP + RI, furrow planting in row intercropping; CA + RI, compost application in row intercropping; and FP + CA + RI, furrow planting with compost application in row intercropping.

4. Discussion

The study demonstrated that cropping systems significantly affected gravimetric soil moisture content and soil temperature at Haramaya during the 2013 main cropping season. The most integrated climate resilient cultural practices generally resulted in higher soil moisture and lower soil temperature than the sole planted faba bean. This present observation corroborates the findings of Choudhary *et al.* (2012) and

Naresh *et al.* (2014) who reported that higher soil moisture and lower soil temperature for maize-cowpea intercrops than for maize sole crop. Dahmardeh and Rigi (2013) found that maize-green gram intercrops had lower soil temperature than sole cropped maize. Similarly, El Naim *et al.* (2013) reported that sorghum-cowpea intercrops resulted in higher soil moisture content over a sorghum pure stand.

Increase in soil moisture and reduction in soil temperature due to the most integrated climate resilient cultural practices of maize-faba bean planting might be explained by high canopy cover and early enclosure of the ground and less light penetration in intercrops. This, in turn, might reduce soil temperature and rate of evaporation and, further, increase soil moisture. Similarly, Dahmardeh and Rigi (2013) and Ghanbari *et al.* (2010) noted that reduced soil moisture content in the sole crop of maize was due to high evaporation potential as a result of lower soil cover. There was more shading in the soil surface in intercropping at high ratio of planting that may have caused low evaporation and high moisture in soil causing low soil temperature (Ghanbari *et al.*, 2010). Olasantan and Babalola (2007) observed that mixed stands reduced soil temperature and increased soil moisture due to ground cover in melon-maize or cassava intercropping, which consequently led to reduction in solar radiation, diurnal soil temperatures, and evapotranspiration.

Plant height was strongly influenced by cropping systems both in 2012 and 2013. At both Haramaya and Arbarakate locations, intercropping and intercropping integrated treatments tended to have taller plants of faba bean, which might be due to severe competition between faba bean and maize to reach and capture light and shading of maize. Both faba bean varieties sown at both locations grew taller in 2013 than in 2012 since the latter cropping season was characterized by a relatively lower precipitation. Previous studies also indicated that plant height of faba bean increased when intercropped with safflower (Abo-Shetaia, 1990); taller faba bean plants were recorded for maize-faba bean row intercropping than sole cropping (Tilahun, 2003). Similarly, Peksen and Gulumser (2013) found that bean-maize row intercropping resulted in the growth of taller plants than sole bean cropping due to more competition for light in the latter. Megawer *et al.* (2010) also reported that lupine underwent shading of barley canopy as a result of interspecific competition for light and exhausted most energy in elongation in barley-lupine intercrops.

Lower grain yields of faba bean were harvested in 2012 than in 2013 possibly due to erratic distribution and early cessation of rainfall starting from the second week of September, which may have caused terminal stress in pod formation and pod filling growth stages of faba bean. Similar results were reported by Ali *et al.* (2013) who found that poor distribution and early termination of rainfall during the cropping season caused moisture deficit and adversely affected productivity. Ghassemi-Golezani *et al.* (2009) also pointed out that water deficit can reduce dry matter accumulation, crop growth rate and relative growth rate and, consequently, reduced grains per plant and grain weight of faba bean. The present data demonstrated that non-intercropped and sole cropped plots produced higher grain yield than other resilient cultural practices, implying intercropping strongly influenced faba bean grain yield. These treatments also generally gave heavier seed weights. Tilahun (2003) found in maize-faba bean intercropping that sole planting gave higher faba bean grain yield than maize-faba bean intercrops. In common bean-maize double intercropping, Tamado *et al.* (2007) showed that sole cropped common bean gave significantly higher seed yield than intercropped bean. Similar results were also reported by Fininsa (1997) in bean-maize mixed and row intercropping.

Possibly higher grain yields and heavier 100-seed weights of faba bean harvested from non-intercropped and sole planting plots in this study might be related to availability of more nutrients and less inter-specific competition in sole crops for available resources than the intercropping systems. In addition, maize plants might have shaded faba bean due to its stature in intercropping and reduced the amount of light transmission required for growth that would result in etiolated growth and poor pod setting in faba bean. In agreement with this current finding, Adeniyan *et al.* (2007) and Khan *et al.* (2012) identified that competition for nutrients, moisture, space and solar radiation was responsible for yield reduction in intercrops. Huaggaard-Nielsen and Jensen (2001) also reported greater competitive ability of barley when intercropped with pea, and wheat when intercropped with chickpea for resources may cause shading and, thereby, reduce growth in the legume resulting in low yields.

Earlier studies also revealed that light interception was one of the yield limiting factors in intercrops. Accordingly, Yilmaz *et al.* (2008) indicated that soybean-maize intercrops had lower light interception and, as a result, severe competition occurred. In maize-cowpea intercrops, Legwaila *et al.* (2012) reported that maize shadowed cowpeas and reduced the amount of light required to stimulate flower production in cowpeas; and Khan *et al.* (2012) reported a similar observation in maize-mungbean intercrops. Furthermore, the superiority of sole lupine over barley-lupine intercropping systems was due to shading and lupine exhausted most energy in elongation and vegetative growth and less during grain filling period (Megawer *et al.*, 2010).

The present findings revealed that furrow planting with compost fertilization gave the highest faba bean grain yield, followed by compost fertilization. Among intercropping integrated treatments, compost fertilization in row intercropping generally produced higher faba bean grain yield and lower relative grain yield loss than other treatments. These treatments also reduced both faba bean rust and chocolate spot severity (Terefe *et al.*, 2015; Terefe *et al.* submitted). In 2012, furrow planting integrated intercropping systems led to lower relative grain yield losses, suggesting the vital role of furrow planting in moisture stress areas and compost fertilization to maintain productivity. This could reduce crop failure and increase resilience to climate variability effects. Several authors also reported yield gains due to compost application on different crops. Riahi *et al.* (2009) showed that compost amendments gave greater total and marketable yields of tomato. In their study on the influence of organic fertilization on maize and legumes, Bilalis *et al.* (2012) reported the highest legume root diameter, density and dry weight under compost fertilization, where the faba bean had high biomass. Similarly, Adeyeye *et al.* (2014) reported that compost application had a significant effect on all yield parameters of soybean, which were higher than those with no compost.

The high faba bean grain yield due to furrow planting and compost fertilization could be attributed to moisture retention and slow and steady availability of nutrients throughout the crop growth period, which, in turn, might have boosted the faba bean grain yield. Moreover, this treatment might improve soil physico-chemical properties, which might have resulted in loose and friable soil conditions and enabled better yielding capacity. Similarly, Adeyeye *et al.* (2014) noted that an increase in all yield parameters of soybean due to compost application indicates essentiality of N nutrition as a starter for optimum soybean productivity. Bedada *et al.* (2014) indicated that application of compost helps in improving the physico-chemical properties of soil and provides a better soil environment for biological activity. Ngwira *et al.* (2013) also reported that compost use resulted in increases in soil organic C, total N, and available P and soil pH essential for optimum crop growth. This was what was observed from the applied compost in this study where high essential elements were found. Thus, compost fertilization could be an option to agricultural land management practice and climate change adaptation strategies. Studies by Bryan *et al.* (2013) on adaptive strategies by subsistence farmers to climate change also pointed out that composting or manure, intercropping, residues and soil bunds are the most common practices that can increase productivity, soil fertility and increase in water-holding capacity of the soil.

Furthermore, Zemánek (2011) proposed a positive influence of compost on soil water and soil moisture retention. On the other hand, Xiaoli *et al.* (2013) found an increase in soil moisture, grain yield and harvest index of corn and water use efficiency in an integrated furrow-applied mulching system. The system is likely to reduce soil evaporation loss. Hu *et al.* (2014) also reported that rainwater-harvesting through mulching, ridging and furrow planting increased water use efficiency and, hence, an increase in marketable potato yields. These systems in different orientations also accumulated higher dry matter and increased relative growth rate, gave the highest tuber yield and increased water use efficiency through reduced evapotranspiration (Qin *et al.*, 2014). Moreover, Feng *et al.* (2012) indicated that ridge-furrow planting system harvested more rain water and conserved soil moisture and, consequently, increased dry matter and grain yield of *Elymussibiricus*.

Faba bean grain yields from intercrops were lower than their respective sole planting, and the total land productivity was much higher in intercrops than in sole crops, which is supported by total LER values (observed to be more than one). The values computed in 2013 were even higher than the values from previous studies. This finding agrees with the results of Agegnehu *et al.* (2008) who found that in barley-faba bean intercropping, all intercrops had greater LER values than in sole crops of both components. Tilahun (2003), Minale *et al.* (2002) and Tilahun *et al.* (2012) also reported greater computed LER values than one in all the intercrops of maize-faba bean intercropping. Similarly, Dusa and Stan (2013) reported greater LER values in oat-pea or lentil intercropping systems, implying the efficiency of resource use in intercropping relative to sole crop. The high intercropping advantage during the specified cropping season could be due to resource use efficiency; decrease in diseases, pests and weed build-up (Jensen *et al.*, 2010); and soil moisture retention and cooled soil temperature as revealed by this study.

The overall results of the study revealed that faba bean performed better and produced relatively higher grain yield at Arbarakate than at Haramaya in 2013. This might be attributed to differences in the suitability of the two locations for growth and development of the crop. Thus, Arbarakate is characterized by extended period of rainfall, higher altitude and better soil conditions, which may have favored the growth and development of the crop over Haramaya. Tamene (2015) also reported that environmental effects accounted for 73.6% of the total yield variation among faba bean genotypes evaluated compared to genotype and genotype x environment interactions. Concurrent with the results of this study, an experimental location at higher altitude with high rainfall amount and even distribution resulted in higher grain yield and dry biomass weight in faba bean varieties tested compared to an experimental location with a relatively lower altitude (Ashenafi and Mekuria, 2015).

5. Conclusions

Intercropping integrated climate resilient cultural practices significantly increased soil moisture content by cooling the soil temperature and enhancing soil moisture content compared to sole faba bean planting. These practices also generally led to the production of higher faba bean grain yields per unit area. Sole planting and non-intercropping treatments produced significantly higher total faba bean grain yield than that of both intercropping and intercropping integrated treatments. However, the land productivity index indicated the advantages of intercropping of faba bean and maize. Among intercropping integrated treatments, compost fertilized systems produced the highest faba bean grain yield, particularly compost fertilization in row intercropping. Moreover, the overall faba bean grain yield obtained from compost fertilization along with furrow planting or in combination with other climate change resilient cultural practices enhanced productivity of faba bean in Hararghe highlands. It is, therefore, concluded that integrated climate resilient cultural practices are proved to be more productive than sole cropping of the two faba bean varieties tested and with promising capacity to mitigate effects of climate variability. Practicing the integrated climate resilient cultural practices may benefit farmers through increased productivity and can diversify produces and food resources via reduced inputs and non-chemical means in the face of climate variability. These practices are economical and eco-friendly for maintaining productivity and managing faba bean diseases. It is suggested to further directly investigate the effect of compost on yield and quality of crops as well as on soil physico-chemical properties.

6. Acknowledgements

The study was financed by the Swedish International Development Agency (SIDA) and Haramaya University, Ethiopia. We thank Mr. Getahun Tessema (Farmers' Development Agent, Arbarakate) and Miss Woinshet Feleke, Mr. Berhanu Asfaw and Mr. Tefera Berhanu, School of Plant Sciences, Haramaya University, for their assistance during field follow up and data collection, and staff members of West Hararghe Zone Bureau of Agriculture and Rural Development who facilitated the allotment of experimental land at Arbarakate. We are also very thankful to farmers and daily laborers who participated in the field experiments.

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