Combining Ability of Maize Inbredlines for Secondary Traits of Adaptation to Multiple Cropping Systems

Alemeshet Lemma* [1] and Firew Mekbib[2]
[1]Melkassa Agricultural Research Center, P.O.Box 436, Adama, Ethiopia; [2]Haramaya University
P.O. Box 138, Dire Dawa, Ethiopia; E-mail: alelgc98@gmail.com

Abstract

*Selecting genotypes based on secondary has been employed in crop improvements to various managments. However their importance in maize breeding has been limited. This study was conducted to identify high yielding maize hybrids and to study combining abilities of maize inbredlines for secondary traits of adaptations to maize-bean intercropping. Maize genotypes (G=42) were planted at two locations in 6x7 α-lattice design as maize-bean intercrop and as sole maize. All data were collected and analyzed for individual Management (M) and Environments (E) followed by across M and E using random model in SAS. Significant G, E, M, Line (L) and Tester (T) effects were observed for most of the traits measured while LxT, ExM, ExG, MxG, ExMxG, MxL, MxT and MxLxT effect for few. Relative reduction (RR) varied from -11.7% to +5.4%. Stalk diameter (SD), Yield (GY), Leaf area/area index (LA/LAI) and Ear height (EH) of the G decreased opposed to Plant height (PH) and Leaf number (NL) in maize-bean intercropping. Heritability (H^2) ranged from 0.49(LAI) to 0.98(EH). General combining ability (GCA) effects for L varied from -0.77** to 0.89** for GY, -54.07** to 95.4** in leaf area (LA); -23.6** to 25.1** in PH, -1.42** to 2.0** in SD and -0.99** to 1.35** in NL. Four hybrids (Entry: 2, 3, 4 and 18) performed well under sole maize and showed resilience under maize-bean intercropping conditions were recommended for possible release. Five lines (L2, L3, L4, L18 and L19) showed desirable GCA effects across managements were identified to start crossing program.*

Keywords: Secondary traits, Line, Tester, Combining Abilities, Management

Introduction

Modern plant breeding majorly focused on developing genotypes targeting superior yield under high input and mono-culture conditions, desirable above ground traits and wider adaptation. However, crops has been grown under low input, inter-cropping or conservation agriculture in the tropics though unexplained physiological, edaphic and genetic mechanisms involved (Francis, 1985; Mahajan et al., 1990). In Ethiopia despite the whole maize growing agro-ecologies are characterized as maize based cropping systems there was neither maize varieties nor breeding programs to developing varieties adapted to maize based cropping systems until recent efforts of testing previously released varieties and developing hybrids that adapt well for both cropping systems (Dagne et al, 2012).

Selecting genotypes based on secondary traits have key role in certain stress environments without relying on yield data (Mahajan et al., 1990; Banziger et al., 2000). Unlike drought, heat or low nitrogen stresses, there are no well-defined secondary traits of adaptation to multiple cropping systems. However plant height, maturity days, stalk lodging and leaf area are considered as secondary traits of adaptation (Mahajan et al., 1990; Smith and Zobel, 1991).

Combining ability (CA) studies has been utilized in maize breeding since the realization of heterosis in hybrid breeding (Griffing, 1956). Selecting inbredlines based on secondary traits' CA under stressed environments is correlated to selection under optimum environments based on yield data (Banziger et al., 2000). The secondary traits of adaptation to multiple cropping systems are targeted to improve the efficiency of resource utilization of the component crops and improve productivity of the maize based cropping systems.

Since the launch of Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) project in 2010/11 the need of getting compatible maize varieties for different cropping systems became important. However there were no breeding programs for maize compatibility improvement for different cropping systems at the time. Therefore the project had focused on testing the already released maize varieties as the immediate solution and later on to establish breeding programs for maize compatibility to different managements. The project identified that the released maize varieties were not responding well to the different cropping systems (Dagne et al, 2012). They identified Melkassa2 and Nasir as the most compatible with good Land Equivalent Ratio (LER) for the Central Rift Valley while the recently released hybrids like MH130, MH140 and MH138Q were all poor in maize-bean intercropping systems. By the second phase of the project hybrids such as BH546 and BH547 were released for their high yield performance under different cropping systems for mid altitude high potential areas (Dagne et al, 2012). However for drought prone areas, the quest for high yielding maize varieties compatible to different cropping systems remain important. Therefore this study was conducted to identify high yielding maize hybrids compatible to different cropping systems and to study combining abilities of maize inbredlines for yield and some secondary traits of adaptations to maize-bean intercrop systems.

Materials and Methods

Melkassa and Ziway have altitude of 1550 and 1637 masl each with sandy loam and silt soil types and received 870 and 826.8 mm annual rainfall, respectively. The study had 42 maize test crosses and 1 bean variety in 100% maize and maize+50% bean intercrop as per the recommendation by Dagne et al. (2012). Each plot had 2 rows of 4m with spacing of 0.75mx0.25m. The bean was planted after 25 days of maize planting with spacing of 10cm between plants. All the inbredlines were from CIMMYT. Two single cross testers were ((CML312/CML442 =Tester A) and (CML202/CML395 =Tester B)) used. Melkassa2 and MH130 were used as maize checks whereas Nasir was the bean variety used as the component variety under the maize-bean intercropping experiment. Melkassa2 and Nasir were used in these experiments since the two were the recommended varieties for maize-bean intercropping in the Central Rift Valley Areas. The maize inbredlines were selected based on their drought tolerance genetic background.

A 6x7 α-lattice design (Patterson and Williams, 1976) with two replications were used. Data were collected for Grain Yield (GY), Leaf Area (LA), Plant Height (PH), Ear Height (EH), Stalk Diameter (SD) and Number of Leaves (NL). ANOVA was conducted following Proc mixed procedure of SAS 9.4 (SAS, 2015) and genotypes were considered as random. The GCA and SCA mean squares were tested against the mean squares of their interactions with locations and managements (Kempthorne, 1957).

Results and Discussions

Mean Performance, Relative Reduction, Variance Components and heritability

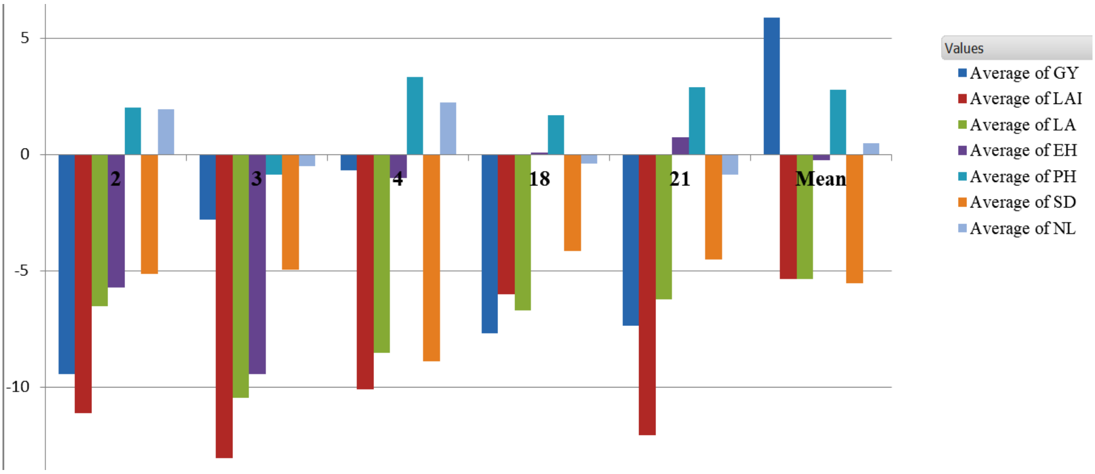
Combined analysis across Managements (M) _ revealed that the mean GY of genotypes was 6.1tha^{-1} and ranged from 4.7tha^{-1} and 7.3tha^{-1}. The results showed that some entries: (3, 7, 16, 17, 20, 24 and 40) were among the top 20 better performing hybrids affected differently by M (Table 1). Yield loss of -27% (Entry20) were recorded under intercrop conditions while it was the second highest yielder under sole maize. The mean Relative Yield Reduction (RR) recorded due to maize-bean intercrop was -6.5% (Table 1). Overall, 29 genotypes depicted a positive RR value which implied the majority are benefited from their interactions in maize-bean inter-crop system whereas twelve which showed negative RR were negatively affected by the component crop. Among the top ten high yielding hybrids only five of the hybrids (Entries: 2, 3, 4, 18 and 21) remained within the top ten in both cropping systems though significant changes were observed in their rank (Fig.1). The result revealed genotypes depicted wide range of genetic variability (Table 1). The result showed maize genotypes were different in their adaptation to the different crop management. Similar to this finding, yield loss ranging from -64 to 88.5% was reported from low N stress as contrasted to optimum N level (Dagne, 2008). Davis and Garcia (1983) reported 15 - 30% maize yield loss when maize was inter-cropped with beans, while an increase in maize yield as sole crop was reported (Muraya et al., 2006).

Mean Leaf Area Index (LAI) of maize genotypes were 0.49 and 0.44 whereas the minimum and maximum were between 0.39-0.58 and 0.37-0.50 under sole maize and maize-bean inter-crop conditions respectively with mean Relative Reduction (RR) of -11.4% due to intercropping. Similarly, mean Leaf Area (LA) for them were 867.34cm2 and 779.13cm^2 ranging from 718.45cm^2-991.53cm^2 and 686.64cm^2-898.35cm^2 orderly. Means ear height (EH)/number of leaves (NL) were 111.99cm/111.43cm and of 12.75/12.87 whereas means of plant heights (PH) were 212.17cm and 224.3cm under sole maize and maize-bean intercrop, respectively. Means for stalk diameter (SD) were 21.07mm and 18.86mm for sole maize and maize-bean inter-crop conditions successively. Relative Reduction (RR) recorded ranged from penalty of -11.7% (SD) due to inter-cropping to increment of +5.4% in (PH) (Table 1 and Fig1). For example minimized LA, LAI, PH and NL in maize varieties are desirable since they allow light penetration and air circulations enhancing photosynthesis in the component crop ultimately enhancing the productivity of the system as a whole (Francis, 1985; Mahajan et al., 1990). It was reported maize genotypes with increased SD resist lodging, on the contrary increased LA, LAI, PH and NL in maize contributed to lodging and ultimately yield loss (Davis and Garcia, 1983; Francis, 1985; Mahajan et al., 1990). The result agreed with previous reports which stated breeding maize for its specific adaptation and compatibility to different maize based cropping systems would improve the productivity of the system as a whole (Francis, 1985; Mahajan et al., 1990) where as others reported negative effects on maize due to maize-bean intercropping or sometimes no significant effects at all (Davis and Garcia, 1983; Francis, 1985; Dagne et al., 2012).

Table1. Combined mean comparison of top ten maize genotypes between crop management systems for GY and secondary traits

				Sole maize			
Entry	**GY**	**LAI**	**LA**	**EH**	**PH**	**SD**	**NL**
2	8.1	0.50	838.69	99.37	193.20	20.12	11.18
20	7.8	0.50	877.96	97.46	211.27	20.45	11.90
18	7.7	0.53	920.66	103.14	209.46	20.24	12.21
38	7.5	0.49	873.54	98.96	207.81	20.70	12.45
39	7.3	0.50	923.45	88.67	190.12	20.87	12.40
3	7.3	0.52	894.63	116.50	224.51	19.61	13.30
21	7.3	0.51	842.73	109.64	211.26	20.77	12.85
4	7.3	0.49	866.13	123.42	215.79	21.32	12.99
22	7.2	0.44	785.20	110.78	203.06	20.25	12.50
40	7.2	0.50	872.63	100.27	209.94	21.04	12.65
Mean	6.4	0.49	867.34	111.99	212.17	21.07	12.75
Minimum	4.9	0.39	718.45	85.23	190.12	19.06	11.18
Maximum	8.1	0.58	991.53	136.92	241.78	23.71	14.34
		Maize-Bean Inter-Crop					
4	7.2	0.40	730.15	120.89	230.59	17.84	13.58
24	7.1	0.45	765.70	119.24	217.03	19.02	14.03
3	6.9	0.40	725.03	96.41	220.57	17.76	13.17
2	6.7	0.40	736.14	88.63	201.18	18.15	11.62
11	6.6	0.47	864.85	113.78	237.99	19.19	13.28
18	6.6	0.47	804.85	103.31	216.64	18.62	12.11
7	6.6	0.47	859.91	130.75	240.73	19.60	14.48
5	6.5	0.47	832.12	121.24	234.93	19.66	13.63
19	6.5	0.43	734.78	87.07	205.47	18.30	11.64
21	6.3	0.40	743.58	111.24	223.86	18.98	12.63
Minimum	5.8	0.37	686.64	81.51	189.88	21.26	11.51
Maximum	4.5	0.50	898.35	136.69	258.47	17.24	14.48
Mean	7.2	0.44	779.13	111.43	224.30	18.86	12.87
%Relative Reduction(RR)	-6.5%	-11.4	-11.3	-0.5	5.4	-11.7	0.9

GY= Grain Yield (tonha^{-1}), LAI=Leaf Area Index (ratio), LA= Leaf Area (cm2); EH= Ear Height (cm); PH= Plant Height (cm); SD= Stalk Diameter (mm); NL= Number of Leaves (no.)



Ent=Entries (2, 3, 4, 18 and 21); Mean= Trial mean; See the remaining traits under Table1.

Fig.1. Relative reductions in GY and secondary traits due to intercropping for five genotypes and the trials means

The genetic variance (GV) for Grain Yield (GY) was 0.31 of which Line Variance (LV) contributed 17% while the Tester variance (TV) contributed 13% and the SCA contributed 7% as opposed to the GCA contributed 30% and the additive genetic variance (AV=1.24) while the dominace varience (DV=0.26) . The GV for SD was 35.72 of which, LV contributed the highest (72%) followed by TV=18% while SCA contributed 5% as compared GCA (53%) at the same time the AVwas 2.11 while the DVwas 0.19. The GV's for LA/LAI were 84071/0.04 while their LV/TV was 1274/0.0005 and 95.07/0.0001 while their GCA variances were 867/676 out of which 3470/ 2706 were due to AV/DV. The GV's for PH/EH were 7180/6258 while their LV were 154/158, their TV (11.27/ 10.32) were not significantly different from Environmental Variance (EnV). Their GCA/SCA variances were 107.4/104 and 14.6/0.0001 while their AV/DV was 430/414 and 58.32/0.0001, respectively. On the other hand GV for NL was 19.2 whereas LV/TV was 0.41/0.07 and GCA of (0.29) AV of (1.18) was observed. Higher broad (H^2) and narrow senses heritability (h^2) were observed for all the studied traits ranging from 91% (LAI) to 98% (EH and PH) and 49% to 98% of the same traits respectively (Table 2). The result showed that sufficient genetic variation observed among the maize genotypes. For all of the studied traits the AV were higher than the DV which indicated that these traits suited well to be improved through selections (Griffing, 1956). High narrow and broad sense heritabilities indicated that selecting inbredlines with desirable GCA and AV were effective to pass its genetic characterestics to the next generations which might be hybrids or synthetics to be used for production under complex cropping systems such as maize-bean intercropping (Griffing, 1956; Berhanu et al., 2017).

Table2. Genetic variances and Heritability of GY and secondary traits across locations and management combined

	Secondary Traits						
Variances	GY	SD	LA	LAI	PH	NL	EH
GV	0.31	35.72	84071	0.0403	7180	19.20	6258
LV	0.17	0.71	1274	0.0005	154	0.41	158
TV	0.13	0.18	95.07	0.0001	19.14	0.07	0.11
SCA_V	0.07	0.05	676	0.0003	14.6	0.02	0.0001
GCA _V	0.30	0.53	868	0.0004	107.4	0.29	104
AV	1.24	2.11	3470	0.0015	430	1.18	414
DV	0.26	0.19	2706	0.0013	58.32	0.08	0.0001
EnV	0.07	0.20	468	0.0003	11.27	0.07	10.32
H^2	96	92	93	91	98	95	98
h^2	79	84	52	49	86	89	98

DS=Stalk Diameter (mm); LA=Leaf Area (cm^2); LAI =Leaf Area Index (ratio); PH= Plant Height (cm); EH=Ear Height (cm); G= Genotype; L=Line; T=Tester; A= Additive; D=Dominance; Er= Error; V= Variances; H2/h2= Broad/Narrow Sense Heritability

Genotype x Environment x Management Effects on Secondary traits

Analysis of Variance (ANOVA) for Environment (E), Management (M) and Genotype (G) showed significant mean squares for most of the studied traits except LAI and EH for E and M, respectively (Table 3). Highly significant mean squares for Hybrids (Hb) and Checks (Ch) Vs Hybrids (ChvsHb) were observed for all the studied traits as compared to the checks (Ch) which showed highly significant mean square for PH and EH. The mean squares for M x G were highly significant for all traits except PH and NL. Significant E x M means squares were observed for EH, SD and NL as well as significant G x E x M mean squares observed for EH and PH (Table 3). The observed variations were mainly due to M followed by E and G for most of the traits. The contribution as a result of G ranged from 1% (SD) to 48% (EH) while E contributed from 1% (LAI) to 74% (NL) and M contributed from 0% (EH) to 96% (LAI). Significant G, E, and M mean squares depicted sufficient genetic variability among the genotypes for maize-bean intercrop compatibility while each E and M were different in classifying the genotypes as per their adaptation. Similarly significant GxE, GxM, ExM and GxExM mean squares implied that substantial rank changes in G performance as E and M changed. Different scientists reported significant G, E, M, GxE, GxM, ExM and GxExM effects for traits like GY, PH, LAI and NL in maize and sorghum crops evaluated under different cropping systems with beans (Davis and Garcia, 1983; Feyera et al., 2014; Solomon et al., 2019). Most of the variations observed were contributed by M followed by E and G for most of the traits (Table 3) which indicated that the observed difference were more due to M and E than the genetic variability. Apparently, Solomon et al., (2019) reported the highest proportions of variations were due to E followed by M and G for the traits they studied showing shift between E and M as opposed to our results which might be due to the difference in number of locations and crop management systems used for this study.

Table3. Combined ANOVA for GY and Secondary traits of maize genotypes across Location and management combined

Source	DF	GY	LAI	LA	EH	PH	SD	NL
E	1	13.64**	0.002	18028**	1524**	3541**	37.2**	17.06**
M	1	23.84**	0.29**	682850**	0.23	12916**	440.7**	2.06*
G	41	3.0**	0.01**	18799**	1405**	1628**	8.43**	4.03**
Hb	39	2.98**	0.01**	17471**	1365**	1529**	8.68**	3.89**
Ch	1	1.69**	0.001	0.12	594.1**	2197**	0.06	1.27
ChvsHb	1	4.39**	0.02**	84923**	3988**	6298**	4.85**	13.64**
E x G	41	0.56**	0.001	1974	66.7	64.07	1.23	0.38
E x M	1	0.50ns	0.001	1494	477.6**	153.09	13.6**	38.75**
M x G	41	1.01**	0.003**	4501**	104.5**	121.41	1.38*	0.41
G x E x M	41	0.52**	0.001	2420	77.25*	131.7*	1.26	0.45
Error	160	0.19	0.001	1523	48.62	86.98	0.88	0.39
CV		7.11	7.09	4.73	6.25	4.28	4.72	4.88
Mean		6.14	0.47	824.8	111.6	218.1	19.94	12.79
H^2		96	93	91	98	98	92	95
h^2		79	52	49	98	86	84	89
% Contribution E		33.7	1	3	52	20	8	74
% Contribution M		58.89	96	95	0	71	91	9
% Contribution G		7.41	3	2	48	9	1	17

GY=Grain Yield (tonha^{-1})E=Environment or Location; M= management; G=Genotype; Hb= hybrids; Ch=Checks, CV= Coefficient of Variation (%); Contrib= proportion of Contribution inflicted by G, E and M on the studied traits (%); LAI=Leaf Area Index (ratio), LA= Leaf Area (cm2); EH= Ear Height (cm); PH= Plant Height (cm); SD= Stalk Diameter (mm); NL= Number of Leaves (no.); H2= Broad Sense Heritability (%); h2= Narrow Sense Heritability (%)

Line x Tester ANOVA for Combining Abilities of maize inbredlines of Secondary traits

Significant Environment (E) and Management (M) mean squares observed for most of the studied traits except Number of Leaves (NL) for E and Ear Height (EH)/ Leaf number (NL) for M (Table 4). The GCA for the Line (L) and Tester (T) were significant for most of the studied traits except LA, LAI and EH for T. The LxT mean squares were significant only for GY, LAI and LA. Apparently, the mean squares of ExM interaction was significant for EH, SD and NL; the MxL interaction was significant for GY, LAI and LA. In addition the MxT interaction was found significant for all traits except GY and NL while the MxLxT interaction was significant for GY, LAI and LA (Table 4).

The genotypic variation due to additive gene effect was much important than the non-additive component for all of the traits contributing from 74% in LAI to 97% in EH. The maximum contribution of GCA (L) was 96% in EH and the minimum was 64% in LAI whereas GCA (T) contributed from 1% in EH to 10% in LAI. On the contrary, the SCA (LxT) contributed the highest 26% in LAI and 20% LA (Table 4). The result depicted that additive genetic variance played very important roles in the inheritance of all traits while the non-additive component was relatively higher in LAI and LA. The result revealed that, the materials can be improved through recurrent selection to generate improved varieties adapted to the intended E and M as it was suggested by (Griffing, 1956). Significant mean squares of MxL for GY, LAI and LA, MxT for LAI, LA, EH, PH and SD, MxLxT for GY, LAI and LA, ExMxLxT for GY depicted the combining abilities of the inbredlines were more affected due to variations in management than environment. Similarly, fsignificant L, T, LXT, LxE, TxE for GY, PH and EH were reported from different sets of experiments conducted under contrasting environments of striga infestation, drought, low-N and their optimum counterparts (Mosisa et al., 2008; Badu-Apraku *et al.*, 2015).

Table4. ANOVA for GY and secondary traits for Lines and Testers across locations and managements combined

Source	DF	GY	LAI	LA	EH	PH	SD	NL
E	1	14.7**	0.002**	20870*	1392*	3236**	38.38*	16.89
M	1	22.13**	0.26**	627799**	2.47	12743**	425.1**	2.30
ExM	1	0.29ns	0.001	1321.4	1143**	158.34	29.42**	71.80**
L	19	3.93**	0.01**	27445**	2721**	2762**	14.76**	6.74**
T	1	19.69**	0.03	30996	131.5	3217**	27.0**	12.74*
L x T	19	1.07*	0.004*	7258*	81.93	228.7	1.55	0.54
E x L	19	0.47**	0.002	2304	55.67	70.92	1.56	0.59
M x L	19	1.59**	0.003**	5038**	96.27	166.5	1.29	0.46
E x M x L	19	0.62**	0.001	1873	79.57	82.97	1.25	0.41
E x T	1	0.48ns	0.0001	783.1	8.34	25.24	0.20	1.37
M x T	1	0.31ns	0.01**	25270**	634.7**	329.8*	2.71*	0.58
E x M x T	1	0.05ns	0.001	182.3	52.71	176.7	0.08	1.62
E x L x T	19	0.66**	0.001	1542	70.45	49.88	0.93	0.15
M x L x T	19	0.50**	0.003**	3162*	90.33	77.55	1.44	0.37
E x M x L x T	19	0.40*	0.001	3005	69.32	159.3	0.96	0.31
Error	160	0.2	0.001	1443	50.00	84.64	0.87	0.44
CV		7.21	6.94	4.59	6.29	4.20	4.66	5.17
Minimum		4.7	0.43	769.64	87.35	195.57	18.58	11.86
Maximum		7.3	0.52	922.04	134.3	244.29	22.01	14.20
%Contribution L_GCA		65.1	64	76	96	87	83	85
% Contribution T_GCA		17.2	10	4	1	5	8	8
% Contribution LXT_SCA		17.8	26	20	2	8	9	7

E=Environment or Location; M= management; G=Genotype; CV= Coefficient of Variation (%); Hb= (hybrids or Crosses) L= GCA due to Lines; T= GCA due to Tester; LxT= SCA; LAI=Leaf Area Index (ratio), LA= Leaf Area (cm2); EH= Ear Height (cm); PH= Plant Height (cm); SD= Stalk Diameter (mm); NL= Number of Leaves (no.)

General Combining ability effects of maize inbredlines for Secondary traits

Inbredlines depicted wide range of variability for their GCA effects, ranging from significantly low to high values (Table 5 and 6). For instance; L2, L3, L4, L18 and L19 showed desirable positive GCA effects for GY. Three inbredlines (L2, L4 and L6) showed significant desirable negative GCA effects for LAI and LA while four inbredlines (L9, L11, L17 and L18) showed significant and positive GCA values for the same traits. Seven lines (L1, L2, L13, L14, L18, L19 and L20) had significant and negative GCA effects for PH and EH while three lines (L7, L8 and L9) expressed significant positive GCA effects for SD. Similarly, six lines (L2, L12, L14, L17, L18 and L19) showed desirable negative and significant GCA Effects for NL (Tables5 and 6). The Tester showed significant GCA effects for all traits except for EH. Tester2 (T2) showed significant and desirable GCA effects for most of the studied traits while Tester1 (T1) depicted the opposite. In general, five inbredlines (L2, L3, L4, L18 and L19) showed desirable GCA effects constantly for the studied traits across the two managements (Tables 5 and 6). Significant GCA effects of L showed the genetic variability among the used inbredlines in these experiments. For e.g., from our study 3-7 lines depicted desirable GCA effect for each trait. Positive and significant GCA values are required to select inbredlines for improving traits with the highest economic significance such as GY; PH,EH and LA however inbredlines with significant negative GCA values for PH, EH and LA are required for their compatibility to maize-bean intercropping system. Compatibility is basically reflected as positive Land Equivalent Ratio (LER) which is a function of good productivity of each component crops (Francis, 1985; Mahajan et al., 1990). For example minimized LA, LAI, PH and NL in maize varieties are desirable since they allow light penetration and air circulations enhancing photosynthesis in the component crop ultimately enhancing the productivity of the system as a whole (Francis, 1985; Mahajan *et al.*, 1990). Maize genotypes with increased SD resist lodging, on the contrary increased LA, LAI, PH and NL in maize contributed to lodging and ultimately yield loss (Davis and Garcia, 1983; Francis, 1985; Mahajan et al., 1990) which suggested that negative GCA effects are more desirable for all traits except GY and SD. Despite lack of report on combining abilities of maize inbredlines under sole maize and maize–bean intercrop interactions, findings from (Mosisa et al., 2008; Badu-Apraku et al., 2015; Berhanu et al., 2017) showed that inbredlines depicted variability in their performance under contrasting environments.

Table 5. GCA Effect for GY and secondary traits of adaptation for Lines and Testers across managements

						Sole Maize					
Line	**GY**	**LA**	**PH**	**SD**	**NL**	**Line**	**GY**	**LA**	**PH**	**SD**	**NL**
1	0.54*	-3.14	-2.29*	0.1	-0.45	**14**	-0.7**	-18.51	-18.03**	-1.68**	-0.75*
2	1.27**	-58.72*	-14.86**	-0.91	-0.95**	**15**	-1.1**	-70.55**	12.82**	-1.03	0.36
3	0.57*	10.87	3.17**	-0.22	0.51	**16**	0.3	16.61	17.44**	0.82	0.62
4	0.19	-50.04*	-2.75*	0.03	0.2	**17**	0.2	47.41*	3.89**	-0.19	-0.73*
5	-0.25	-21.29	3.19**	0.54	0.14	**18**	1.15**	24.8	-4.61**	-0.68	-0.48
6	-0.59*	-72.89**	-6.14**	0.26	-0.001	**19**	0.63*	29.59	-25.9**	-0.72	-0.83*
7	-0.8**	45.98*	11.19**	1.81**	0.7*	**20**	1.08**	7.64	-2.22*	-0.38	-0.49
8	-0.57*	-34.65	24.1**	2.18**	0.79*	**T1**	0.24**	19.3**	4.06*	-0.39*	-0.26*
9	0.05	67.65**	21.49**	2.05**	1.44**	**T2**	-0.24**	-19.3**	-4.06*	0.39*	0.26*
10	-0.43	16.39	1.06	0.88	0.45	SE_L	0.25	21.73	4.8	0.54	0.34
11	-1.06**	94.31**	-1.36	-0.36	0.25	SE_T	0.08	6.87	1.52	0.17	0.11
12	-0.35	-16.05	-2.28*	-1.52**	-0.35	SE(Dif)L	0.35	30.73	6.78	0.77	0.48
13	-0.13	-15.42	-17.91**	-0.99	-0.42	SE(Dif)T	0.11	0.59	0.28	0.09	0.07
						Maize-Bean Inter-crop					
1	0.21	-28.7	-4.5	-0.08	-0.47	**14**	-0.47*	-11.7	-13.3**	-1.12**	-0.37
2	0.54**	-50.7**	-21.7**	-0.36	-0.96**	**15**	-0.49*	10.2	6.9	-1.19**	0.24
3	0.31	-49.5**	-6.6	-1.1**	0.43	**16**	-0.06	22	19.1**	0.61	0.31
4	1.2**	-35.7*	-1.5	-0.44	0.88**	**17**	-0.09	60.3**	6.5	-0.08	-0.69*
5	0.01	16.7	2.7	0.76*	0.52	**18**	0.45*	38.8*	-5.8	-0.06	-0.71*
6	0.01	-42.9*	-8.8	-0.31	-0.11	**19**	0.4*	-36.3*	-21.7**	-0.57	-1.03**
7	-0.38*	56.6**	14.8**	0.96**	1.23**	**20**	-0.37*	-43.9*	-18.4**	0.14	-0.34
8	-0.16	-21.7	21.9**	1.75**	0.32	**T1**	0.28**	1.9	2.41*	-0.19*	-0.16*
9	-0.6**	80.7**	28.3**	2.05**	1.28**	**T2**	-0.28**	-1.9	-2.41*	0.19*	0.16*
10	-0.71**	-28.6	-0.9	-0.43	0.05	SE_L	0.18	16.99	4.49	0.34	0.28
11	0.12	97.9**	10.9*	0.44	0.5	SE_T	0.06	5.37	1.42	0.11	0.09
12	-0.05	-35*	1.1	-0.49	-0.85**	SE(Dif)L	0.57	24.03	6.35	0.48	0.39
13	0.12	1.3	-8.8	-0.5	-0.22	SE(Dif)T	0.08	7.6	2.01	0.15	0.12

L= GCA due to Lines; T= GCA due to Tester; LXT= SCA; LAI=Leaf Area Index (ratio), LA= Leaf Area (cm2); EH= Ear Height (cm);
PH= Plant Height (cm); SD= Stalk Diameter (mm); NL= Number of Leaves (no.), SE= Standard Error; SE (Dif) = Standard Error difference

Table 6. GCA Effect for secondary traits of adaptation for multiple cropping systems across location and managements

	Traits						
Line	**GY**	**LAI**	**LA**	**EH**	**PH**	**SD**	**NL**
1	0.36	-0.01	-15.08	-7.3*	-3.3	0.004	-0.48
2	0.89**	-0.03*	-54.07**	-11.6**	-18.1**	-0.71	-0.99**
3	0.48*	-0.02	-18.12	-3.2	-2.1	-0.61	0.42
4	0.68**	-0.02	-41.55*	7.6*	-2	-0.21	0.57*
5	-0.11	-0.001	1.11	6.4	3.8	0.8*	0.36
6	-0.31*	-0.04*	-57**	-0.7	-7.5	-0.05	-0.03
7	-0.54*	0.03*	50.14*	20.6**	12.6*	1.46**	0.96**
8	-0.32	-0.01	-29.23	16.8**	22.6**	1.97**	0.51
9	-0.3	0.05**	73.81**	15.9**	25.1**	2**	1.35**
10	-0.58*	-0.01	-4.58	7.9*	0.6	0.29	0.24
11	-0.5*	0.04*	95.4**	3.4	4.9	0.002	0.38
12	-0.19	-0.01	-27.3	-5.9	-0.6	-1.01*	-0.58*
13	-0.07	-0.01	-5.89	-8*	-12.9**	-0.82*	-0.29
14	-0.58*	1E-04	-14.11	-15.7**	-15.8**	-1.42**	-0.58*
15	-0.77**	-0.02	-30.97	0.5	9.2	-1.09*	0.31
16	0.13	-0.001	16.58	21.9**	18.1**	0.69	0.49
17	0.07	0.05**	56.62**	5.4	5.6	-0.05	-0.71*
18	0.83**	0.03*	30.36*	-10.1**	-5.7	-0.34	-0.6*
19	0.52*	-0.01	-3.24	-25.1**	-23.6**	-0.67	-0.95**
20	0.32	-0.02	-22.86	-18.5**	-10.9*	-0.25	-0.37
T1	0.26**	0.01	10.2	-0.7	3.28**	-0.3*	-0.21*
T2	-0.26**	-0.01	-10.2	0.7	-3.28**	0.3*	0.21*
SE_L	0.22	0.02	19.51	3.5	4.7	0.47	0.31
SE_T	0.07	0.01	6.17	1.1	1.47	0.15	0.1
SE(Dif)L	0.31	0.023	27.593	4.93	6.595	0.665	0.442
SE(Dif)T	0.10	0.01	8.73	1.56	2.09	0.21	0.14

Note: Parameters are illustrated under Table5.

Conclusion and Recommendation

Even though the year, management and locations involved in this experiment is very limited, the significant interaction effect between G, M and E for those traits showed the need to start breeding for specific than wider adaptation. However breeding for specific adaptation is only effective if the market size for such varieties are large enough and the seed sector is well established. The existing breeding strategy in Ethiopia is to develop varieties adapted to the multiple biotic and abiotic stresses and suitable to mono cropping system which completely ignores small scale farmers producing maize under different cropping system. Therefor farmers were left with no choice but to use either their own land races, old varieties or those varieties released for mono cropping which usually resulted in poor production or productivity of the maize based cropping system. The result from this research showed that it is possible to develop high yielding varieties across different maize based cropping systems which gives alternative modern varieties for small scale farmers practicing multiple cropping system so that they can improve the low maize based cropping system production and productivity without compromising the production and productivity of those farmers growing maize as a mono crop. Therefore we recommend four maize hybrids (Entry 2, 3, 4 and 18) varieties that performed well under sole maize and showed resilience under maize-bean intercropping conditions for possible release. These varieties were not only the top performers consistently across the two cropping systems but also were significantly high yielder than the recently released hybrid check and the recommended check for maize-bean intercropping compatibility in the central rift valley areas of Ethiopia.

Despite lack of any lines to be used as checks for comparing the performance of the lines used in this experiment, five inbredlines (L2, L3, L4, L18 and L19) depicted desirable genetic variations across the two cropping systems consistently. Therefore we recommend these inbredlines to start crossing program to develop hybrids and synthetics that are suitable for both mono crop and maize based diverse cropping systems within the drought stress affected maize growing agro-ecology of Ethiopia.

Acknowledgments

We are indebted to CIMMYT and ACAIR for funding this research through Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) project. We would like to extend our gratitude to the Ethiopian Agricultural Research Institute (EIAR) and Melkassa Research Center (MARC) for the provision of the logistics.

References

Badu-Apraku, M., Fakorede, A.B., Talabi, A.O., Oyekunle, M. Akaogu, I.C., Akinwale, R.O., Annor, B., Melaku, G., Fasanmade, Y. and Aderounmu, M. 2015. Gene Action and Heterotic Groups of Early White Quality Protein Maize Inbreds under Multiple Stress Environments. Crop Sci., 56: 183–199. https://doi.org/10.2135/cropsci2015.05.0276.

Banziger, M., Edmeades, G.O., Beck, D. and Bellon, M. 2000. Breeding for Drought and Nitrogen Stress Tolerance in Maize: From Theory to Practice. Mexico, D.F.CIMMYT.

Berhanu T., Yoseph B., Mugo S., Olsen M., Oikeh S., Juma C., Labuschagne M. and Prassana B. 2017. Combining ability and testcross performance of drought-tolerant maize Inbredlines under stress and non-stress environments in Kenya. Plant Breed.136:197–205. https://doi.org/10.1111/pbr.12464.

Dagne Wegary Gissa. 2008. Genotypic variability and combining ability of quality protein maize inbred lines under stress and optimal conditions. A dissertation Submitted in accordance with the academic requirements for the degree of Philosophiae Doctor, Department of Plant Sciences (Plant Breeding) Faculty of Natural and Agricultural Sciences University of the Free State, South Africa.

Dagne.W., Temesgen, A., Solomon A., Solomon J., Alemu T. and Hidoto, L. 2012. Towards Sustainable Inteification of Maize-Legume Cropping Systems in Towards Sustainable Inteification of Maize-Legume Cropping Systems in Ethiopia. In: Mosisa W., Twumasi-Afriyie, S., Legesse W., Berhanu T., Prasanna, M. P., Gezehagn B., Dagne W. (Eds.): Meeting the challenges of global climate change and food security through innovative maize research. Proceedings of the Third National Maize Workshop of Ethiopia. April 18–20, Addis Ababa, Ethiopia.

Davis, J. H. C. and Garcia, S. 1983. Competitive ability and growth habit of indeterminate bea and maize for intercropping. Field Crop. Res., 6:59–75.https://doi.org/10.1016/0378-4290(83)90048-5.

Feyera M., Tesfaye, K. and Wortmann. C. S. 2014. Dry soil planting of sorghum for vertisols of Ethiopia. Agronomy Journal, 106(2):469–474. https://doi.org/10.2134/agronj2013.0472.

Francis, C.A. 1985. Variety development for multiple cropping systems. Crit. Rev. Plant Sci., 3:133-168.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci., 9:463-493.

Kempthorne, O. 1957. An Introduction to Genetic Statistics. John Wiley and So, Inc., New York.

Mahajan,V.M., Singh, M., Sarma, B.K. and Patel, C.S.1990. Identification of Characters to breed varieties of maize for intercropping with dry bean. Crop Improv.17 (2):150-154.ISSN. 0256-0933.

Mosisa W., Banziger, M., Friesen, D., Schulte, G., Horst, W. J., and Vivek, B. S. 2008. Relative Importance of General Combining Ability and Specific Combining Ability among Tropical Maize (Zea Mays L.) Inbreds under Contrasting Nitrogen Environments. Maydica, 53:279–288.

Muraya, M., E.O.Omolo and C.M.Ndirangu.2006. Development of high yielding synthetic maize (Zea mays L.) varieties suitable for intercropping with common bean (Phaseolus vulgaris L.). Asian Journal of Plant Sciences.5:163-169. DOI:10.3923/AJPS.2006.163.169.

Patterson, H.D. and Williams, E.R. 1976. A new class of resolvable incomplete block desig. Biometerica, 63:83-89.

SASItitute, Inc. 2015. Base SAS 9.4 procedures guide fifth Edition, Cary, NC: proprietary Software, SAS Ititute, Inc., Cary, NC.

Smith, M.E. and Zobel, R.W. 1991. Plant Genetic Interaction in Alternative Cropping Systems : Consideration for Breeding Methods. Crop Science Society of America and American Society of Agronomy, Plant Breeding and Sustainable CSSA special publication no.8:57-81.Agriculture, https://doi.org/10.2135/cssaspecpub18.c4.

Solomon S., Rachaputi, R., Fekybelu, S., Chauhan, Y., and Prasanna, B. 2019. Exploiting genotype x environment x management interactio to enhance maize productivity in Ethiopia. Eur. J. of Agron., 103:165–174. https://doi.org/10.1016/j.eja.2018.12.011.