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Productivity of farmer-preferred maize varieties intercropped with beans in semi-arid Kenya

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Abstract

Farmers in the semi-arid regions grow drought tolerant maize varieties and practice maize-legume intercropping. A study was conducted in Machakos, Mwea and Waruhiu in 2008 short rains and 2009 long rains to determine the performance of maize varieties currently grown in semi-arid regions and their compatibility with beans. Sixteen maize varieties were grown as sole crops or intercropped with beans. The experiments were laid out in randomized complete block design with split plot arrangement and replicated three times. Maize variety and maize plus beans intercrop system were assigned to main and sub-plots, respectively. Using land equivalent ratio (LER) and monetary advantage (MA) indices, productivity of intercropping was evaluated. Results indicated that varieties KCB, Katumani, DHO 1, DHO 2, DK 8031 and Duma 43 were suitable for Mwea and Waruhiu. They tolerated or escaped drought by maturing early. Further, these varieties were compatible with beans in an intercrop system. However, bean yield was significantly affected by maize component in intercrop system and declines of 52% to 59% were observed. Despite the yield reduction of beans in intercropping, this system was shown to be economically viable according to LER and MA indices. All maize varieties failed to produce a crop in Machakos in two seasons. Increased food production in semi-arid areas requires adoption of drought escaping and tolerant varieties and maize-bean intercropping systems. However, areas with severe droughts like Machakos and adjoining regions of south-eastern Kenya require alternative maize varieties or crop species that are more drought tolerant than those currently recommended.

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Introduction

Food crisis may have receded at global arena but within eastern and southern Africa and particularly Kenya, food deficits persist due to low production hence stubbornly high food prices. Suprisingly, these high food prices have not translated to increased production at producer level. Low production has been occasioned by recurrent droughts whose devastating effects are most felt in semi-arid areas (de Graaff *et al*., 2011). In these semi-arid areas, crop failure has been augmented by declining soil fertility (Diallo *et al*., 2004) and continuous cultivation on fragile soils (Gachimbi *et al*., 2002; Mafongoya *et al.,* 2006; Nyariki, 2007). In dry agro-ecologies, drought and poor soil fertility alternate at the same site within the same season (Rockstrom *et al*., 2009). Consequently, rainfall variability from season to season has been shown to reduce crop yields in semi-arid eastern Kenya (Kinama *et al.,* 2007). For instance, maize and bean yields have considerably declined from a potential of 6 t ha^{-1} and 5 t ha^{-1} to less than 1 t ha^{-1} and 0.5 t ha^{-1}, respectively (Jagtap and Abamu, 2003). Maize and grain legumes are important food crops in the Kenya and are common practice with resource poor farmers in semi-arid areas. Maize is the main and preferred food staple with per capita consumption, averaging 125 kg $person^{-1}$ $year^{-1}$. In years of surplus, maize is also an important source of income to many farmers especially in paying school fees and meeting other family needs. Legumes, especially beans, are an important source of cheap dietary protein and often attract good market prices (Rao and Mathuva, 2000).

To cope with vagaries of drought, farmers have adopted drought tolerant maize varieties and maize-legume intercropping as a risk diversification strategy (Muthamia *et al*., 2001). Maize-bean intercrops often assure farmers some yield per unit area. Breeding activities by the Kenya Agricultural Research Institute, Kenya Seed Company and private seed companies have produced what are considered to be drought tolerant maize varieties for these semi arid areas. Additionally, the National Drylands Research Centre-Katumani has developed drought tolerant bean varieties which include the Katumani Bean series. Among these bean series, Katumani Bean 1 (KB 1) is a widely adopted variety for intercrop and sole crop systems in the semi-arid areas (Katungi *et al*., 2010).

Despite efforts to deploy drought tolerance in maize and in addition tailored cropping systems, crop failures due to drought persist. Besides, a significant knowledge gap exists in the adaptability of the currently grown varieties and the extent of drought tolerance of the so called drought tolerant maize varieties recommended for the semi arid regions. Further, farmers may not be growing what is really recommended for these regions. Maize-bean intercrops, which are most prevalent in these areas, may not necessarily give the best returns in terms of yield or cash because farmers do not necessarily select the most compatible maize varieties for intercropping (Muraya *et al*., 2006). Moreover, studies on maize-bean intercropping have highlighted contrasting results on the effect of intercropping on maize and bean yields (Tsubo *et al*., 2003).

It is imperative that drought tolerant maize varieties and maize-bean compatible varieties are required to address persistently low production in semi-arid areas of Kenya. Therefore, this study was designed to determine the agronomic performance of maize varieties that are currently grown in the semi-arid areas and to determine the compatibility of these maize varieties with KB 1 bean variety under an intercrop system.

Materials and methods

Experimental sites

Field experiments were carried out during the short rains (November 2008 to February 2009) and the long rains (April to July 2009) in three sites, namely: Machakos, Mwea and Waruhiu. Machakos is located in the Lower Midlands (LM4) agroecological zone with annual rainfall range of 400 – 500 mm while Mwea is localed in the Lower Midlands (LM4) and receives 450 – 500 mm of rainfall annually. Waruhiu is located in the Upper Midlands (UM2) and receives annual rainfall of 1200 to 1400 mm.

Treatments and experimental design

Trial materials comprised sixteen maize varieties grown in the semi-arid regions and a common intercropping bean variety Katumani Bean 1 (KB1). The test maize varieties comprised the Five series hybrids: H513, H515, H516; hybrids H614D, Duma 43, DK 8031, pioneer 3253; the dryland hybrids including DHO1, DHO2, DHO4; the Pannar series consisting of Pannar 77, Pannar 7M, Pannar 4M, Pannar 67; and composites Katumani Composite B (KCB) and Katumani.

The experiments were laid out in a randomized complete block design with a split plot arrangement and replicated three times. Maize varieties formed the main plots and the cropping system (either sole crop or intercrop) formed the subplots. The experimental plot sizes were 5 m by 6.75 m and in the intercrop subplots, one row of beans was grown between two rows of maize with intra-row spacing of 25 cm. Maize was sown at a hill spacing of 75 cm by 30 cm. The companion crops were sown at the same time at the onset of rains.

The land was ploughed and harrowed to a moderate seedbed tilth and soils were sampled before planting at 30 cm depth and analyzed for pH, carbon, CEC, macronutrients and micronutrients. Two seeds were planted per hill and thinned to one plant per hill after emergence. Fertilizer NPK 20-20-0 was applied at planting in each hill at the rate of 25 kg N ha^{-1} and 25 kg P_2O_5 ha^{-1}. At flowering maize was top dressed with 25 kg ha^{-1} N. The fields were kept weed free by hand weeding using hoes. Bean fly was controlled using Sumithion super® with active ingredients: 250 g L^{-1} fenitrothion and 12.5 g L^{-1} esfenvalerate.

Data collection

Data collected included bean nodulation, maize phenological development, yield and yield components. The intercropping advantage was assessed using the land equivalent ratio, (LER) and monetary advantage indices, (MAI). As a result of severe weather conditions during 2008 short rains in Mwea and Waruhiu, the bean component dried up at seedling stage before any data could be collected. On the other hand, no data on both crops could be collected in Machakos during 2008 short rains but bean yield data was obtained before the crop dried up during 2009 long rains.

Determination of bean nodulation and seed yield

Three bean plants were randomly selected for nodule count and biomass accumulation at 21 days after emergence and at 50% flowering. The bean plants were dug up gently, washed with water and the nodules recorded for each plant. At physiological maturity, the beans were hand harvested in each plot in an area equivalent to 10.5 m^2 and seed yield was obtained after drying the beans to 15% seed moisture content.

Determination of maize grain yield and yield components

At physiological maturity in both seasons, maize was hand harvested from four rows of each plot equivalent to 13.16 m^2. The outer rows were regarded as guard rows and therefore not harvested. Grain and stover were separated. Eighteen randomly selected cobs per plot were used for determination of maize yield components including number of kernel rows per cob by physical counting.

Assessment of intercropping productivity and monetary value

Grain yield of maize and beans was used to calculate Land Equivalent Ratios (LERs) and Monetary Advantage Indices (MAI) as indicators of the productivity of the intercrop system. LER was calculated as below (Mead and Willey, 1980):

$$LER = \left(\frac{Yield\ of\ intercrop\ maize}{Yield\ of\ solecrop\ maize}\right) + \left(\frac{Yield\ of\ intercrop\ beans}{Yield\ of\ solecrop\ beans}\right)$$

If LER =1, then there is no advantage of intercropping. If LER < 1 then intercropping reduces total yield and therefore not advantageous. If LER >

1, intercropping increases total yield thus advantageous.

MAI was calculated as follows:

$$MAI = Value\ of\ combined\ intercrop\ yield \times \frac{(LER - 1)}{LER}$$

The higher the MAI value, the profitable is the intercropping system. Average farm gate producer prices of Kenya Shillings (Kshs.) 20 per kilo gram (kg) of maize and Kshs. 45 per kg of beans were used to calculate the value of maize and beans (Kenya Agricultural Commodity Exchange, 2009).

Data analysis

All data were subjected to analysis of variance (ANOVA) using Genstat statistical package (Lawes Agricultual Trust, Rothamsted Experimental Station, 2006, version 9). Differences among treatment means were compared using Fisher's Least Significant Difference (LSD) test at 5% probability level (Gomez and Gomez, 1984).

Results and discussion

Agronomic performance of the maize varieties

Significant varietal differences in time to reach 50% anthesis, 50% silking and 50% physiological maturity were observed (Table 1). In the short rains, all varieties recorded significantly shorter time to reach 50% anthesis and silking in Mwea than in Waruhiu except varieties DHO 1, DHO 2, Duma 43, KCB and Pannar 7M. Variety KCB took significantly ($P \leq 0.05$) shorter time to reach 50% anthesis, silking and physiological maturity than all varieties except Katumani, DHO 1, DHO 2 and PHB 3253 while variety H614D took a significantly longer time to flower and mature. DHO 4 was significantly the latest to reach 50% flowering and maturity among the DHO series while no significant differences were noted among the Five and the Pannar series. In summary, varieties Katumani and KCB took the shortest time to flower and mature followed by DHO 1 and DHO 2. The five series, Pannar series, DHO 4, Duma 43, DK 8031 and PHB 3253 had mid-flowering and maturity time while H614D was late maturing. Nonetheless, maize phenological development was not significantly affected by intercropping. Observed earliness in Katumani variety is in line with findings by Mugo *et al.* (1998), who noted that the variety flowered in 66 days. In this study the longest time taken by Katumani to flower was 61 days in Waruhiu. The difference of 5 days could be attributed to differences in weather conditions during the two studies. In their intercropping studies, Moser *et al.* (2006) reported that bean component had no significant effects on time taken by maize to flower and mature. Lack of marked effects of bean component in a maize plus bean intercrop system has been reported in other similar studies (Muraya *et al.*, 2006).

Effect of intercropping on maize grain yield and yield components

Varietal differences in grain yield were noted in the 2009 long rains with no significant differences in the 2008 short rains. Grain yield of DHO 1, DHO 2, Katumani, KCB, H515 and H516 remained relatively stable between the sites in the two seasons (Table 2). The least grain yield was obtained from H614D. Stability in grain yield of DHO 1, DHO 2, KCB and Katumani may be due to their inherent adaptability to semi-arid areas for which they were specifically bred for cultivation. The bean component did not significantly affect maize grain yield and yield components in the intercrop system. Muraya *et al.* (2006), made similar observations indicating that maize performance in pure stands and in intercrop systems does not differ markedly. Further, modeling studies of radiation interception and use in a maize-bean intercrop systems showed that growth efficiency of intercrop maize was equivalent to sole maize (Tsubo *et al.,* 2001; Tsubo and Walker, 2002). However, earlier contradictory observations by Francis *et al.* (1982) and Fininsa (1997) indicated significant maize yield reductions in maize-bean intercrop systems. Lack of significant effects of the bean component in the intercrop system can be explained by the fact that the bean is less competitive. The maize component derives its competitive ability from its more resource use efficient four-carbon dicarboxylic (C4) pathway than the bean's C3 pathway (Gitonga *et al.*, 1999).

Table 1. Mean days after emergence (DAE) to 50% anthesis, silking and physiological maturity of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains.

ariety (V)	DAE to 50% tasseling						DAE to 50% silking						DAE to 50% physiological maturity					
	2008 short rains			2009 long rains			2008 short rains			2009 long rains			2008 short rains			2009 long rains		
	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	58.3	64.6	61.5	43.6	60.6	52.1	61.3	68.0	64.6	49.0	65.0	57.0	86.0	94.0	90.0	102.0	121.6	111.8
DHO 2	59.0	66.6	62.8	42.6	56.0	49.3	62.0	70.6	66.3	47.6	60.3	54.0	88.6	100.3	94.5	99.6	120.6	110.1
DHO 4	63.0	78.6	70.8	51.6	74.6	63.1	66.0	83.3	74.6	57.3	80.3	68.8	104.6	114.0	109.3	129.3	142.6	136.0
DK 8031	65.0	79.0	72.0	49.3	65.0	57.1	68.0	83.6	75.8	55.0	69.6	62.3	96.6	114.0	105.3	113.0	124.3	118.6
DUMA 43	63.6	69.6	66.6	50.6	67.6	59.1	66.6	73.0	69.8	55.0	73.0	64.0	100.3	105.6	103.0	123.0	128.3	125.6
H513	61.0	78.6	69.8	53.0	75.3	64.1	64.0	83.0	73.5	59.0	80.3	69.6	103.6	113.3	108.5	125.3	140.0	132.6
H515	65.6	81.0	73.3	52.3	69.3	60.8	69.0	85.6	77.3	59.0	74.0	66.5	102.3	118.0	110.1	127.6	136.0	131.8
H516	67.0	78.6	72.8	55.3	72.6	64.0	70.0	80.0	75.0	61.3	77.3	69.3	108.3	116.0	112.1	124.0	136.6	130.3
H614D	69.8	82.3	76.0	63.0	81.6	72.3	73.0	88.0	80.5	68.3	86.0	77.1	116.3	122.0	119.1	136.3	151.3	143.8
KATUMANI	53.0	66.0	59.5	35.6	53.0	44.3	56.0	69.6	62.8	40.0	57.3	48.6	82.3	100.0	91.1	96.0	116.6	106.3
KCB	55.3	62.6	59.0	32.0	51.6	41.8	58.1	65.0	61.5	37.0	56.6	46.8	80.0	90.0	85.0	93.3	114.3	103.8
PANNAR 4M	65.0	81.6	73.3	53.3	67.6	60.5	68.0	86.6	77.3	57.6	73.0	65.3	102.1	115.0	108.5	120.6	127.0	123.8
PANNAR 67	64.6	77.0	70.8	54.3	68.6	61.5	67.6	81.0	74.3	59.0	73.0	66.0	102.0	113.0	107.5	115.6	128.0	121.8
PANNAR 77	65.0	77.6	71.3	54.6	73.3	64.0	68.0	81.3	74.6	60.6	77.6	69.1	104.6	116.0	110.3	124.3	129.0	126.6
PANNAR 7M	65.6	73.3	69.5	54.0	76.6	65.3	68.6	77.3	73.0	60.0	80.3	70.1	104.6	114.6	109.6	120.0	138.0	129.0
PHB 3253	56.6	69.6	63.1	53.6	72.3	63.0	59.6	74.0	66.8	58.6	76.6	67.6	102.0	106.6	104.3	123.3	136.6	130.0
Mean	62.3	74.2	68.2	49.9	67.9	58.9	65.3	78.1	71.7	55.2	72.5	63.9	99.0	109.5	104.3	117.1	130.7	123.9
LSD $_{(P\leq 0.05)}$ V		7.5			1.1			7.4			1.1			5			1.1	
LSD $_{(P\leq 0.05)}$ Site		1			0.2			0.9			0.2			1.1			0.2	
LSD $_{(P\leq 0.05)}$ V*Site		7.9			1.3			7.9			1.3			5.9			1.3	
CV %		5.1			1.5			4.8			1.5			3.9			0.7	

LSD: least significant difference; CV: coefficient of variation

Varieties had no significant (P≤0.05) differences in number of ears per plant between the sites except DHO 4 and DK 8031 which had significantly higher number of ears per plant in Mwea and Waruhiu, respectively (Table 2). Site significantly (P≤0.05) affected number of ears per plant over the long rains. However, site-variety interaction was not significant with maize grown in Waruhiu having significantly more ears per plant than in Mwea. In the other hand, number of kernels-rows among the varieties varied significantly (Table 2). Varieties DK 8031, Duma 43, Katumani, KCB, Pannar 77 and PHB 3253 had significantly higher number of kernel-rows per cob in Mwea than in Waruhiu over the short rains. However, over the long rains, varieties DHO 4, KCB and PHB 3253 had significantly higher kernel-rows per cob in Mwea than in Waruhiu. Variety PHB 3253 had significantly higher number of kernel-rows per cob than all varieties while KCB had significantly the least number of kernel-rows per cob than all varieties except Katumani, DHO 2, DK 8031 and the five series. Among the Pannar series, Pannar 7M had significantly more kernel-rows per cob while no significant differences were noted among the DHO series and the Five series. Higher kernel-row counts in Waruhiu could be attributed to sufficient soil moisture received from in-crop rainfall of 89.5 mm against 69.9 mm in Mwea. Consistently high number of kernel-rows of variety PHB 3253, could be the trait being sought for by farmers in the semi-arid regions.

Table 2. Mean grain yield (t ha^{-1}), ears per plant and kernel-rows per cob of sixteen maize varieties grown in Mwea and Waruhiu during 2008 short rains and 2009 long rains.

Variety (V)	Grain yield (t ha^{-1})						Number of ears per plant						Number of kernel-rows per cob					
	2008 short rains			2009 long rains			2008 short rains			2009 long rains			2008 short rains			2009 long rains		
	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1	1.4	1.4	1.4	2.4	2.8	2.6	1.0	1.1	1.1	1.0	1.2	1.1	13.5	11.9	12.7	12.3	12.3	12.3
DHO 2	1.6	1.3	1.4	2.3	2.1	2.2	1.2	1.1	1.2	1.0	1.2	1.1	13.4	12.0	12.7	12.5	12.0	12.2
DHO 4	2.4	1.7	2.1	2.6	2.2	2.4	0.8	1.3	1.1	1.1	1.0	1.0	14.0	12.8	13.4	13.3	12.4	12.8
DK 8031	2.4	1.2	1.8	2.4	1.6	2.0	1.5	1.1	1.3	1.0	1.0	1.0	13.6	12.0	12.8	12.2	12.2	12.2
DUMA 43	1.6	1.5	1.6	3.2	2.5	2.9	1.2	1.3	1.3	1.0	1.1	1.1	13.4	11.4	12.4	12.6	12.2	12.4
H513	2.3	1.4	1.8	2.2	2.5	2.4	1.2	1.0	1.1	1.1	1.1	1.1	12.8	12.8	12.8	12.2	12.1	12.2
H515	1.8	1.2	1.5	2.0	1.9	2.0	1.2	1.0	1.1	1.0	1.1	1.1	13.2	12.0	12.6	12.1	12.2	12.2
H516	2.0	1.5	1.7	2.0	1.8	1.9	1.2	1.0	1.1	1.1	1.1	1.1	12.9	11.8	12.3	12.4	12.1	12.3
H614D	2.0	1.4	1.7	1.2	1.4	1.3	1.2	1.0	1.1	1.1	1.0	1.0	12.7	12.5	12.6	12.7	13.0	12.9
KATUMANI	1.7	1.3	1.5	1.8	2.4	2.1	1.2	1.0	1.1	1.0	1.1	1.1	14.2	11.7	13.0	12.1	11.8	11.9
KCB	1.8	1.4	1.6	2.0	1.7	1.8	1.2	1.1	1.2	1.0	1.0	1.0	12.6	11.2	11.9	12.3	11.1	11.7
PANNAR 4M	2.1	1.5	1.8	2.4	1.8	2.1	1.3	1.1	1.3	1.1	1.1	1.1	13.1	12.2	12.7	12.7	12.7	12.7
PANNAR 67	2.1	1.9	2.0	1.7	2.4	2.0	1.1	1.2	1.2	1.0	1.0	1.0	13.1	12.5	12.8	12.1	11.6	11.8
PANNAR 77	2.1	1.6	1.8	2.0	1.8	1.9	1.1	1.0	1.1	1.0	1.0	1.0	13.9	11.8	12.9	13.4	13.0	13.2
PANNAR 7M	2.1	1.3	1.7	1.9	2.5	2.2	1.1	1.1	1.1	1.0	1.1	1.1	13.7	12.8	13.2	14.1	13.8	14.0
PHB 3253	1.8	1.6	1.7	2.8	1.8	2.3	1.1	1.1	1.1	1.1	1.0	1.0	14.6	13.0	13.8	15.4	13.7	14.6
Mean	1.9	1.5	1.7	2.2	2.1	2.1	1.2	1.1	1.1	1.0	1.1	1.1	13.4	12.1	12.8	12.8	12.4	12.6
LSD $_{(P\leq 0.05)}$ V		NS			0.5			NS			NS			NS			0.6	
LSD $_{(P\leq 0.05)}$ Site		0.1			NS			NS			0.02			0.1			0.1	
LSD $_{(P\leq 0.05)}$ V*Site		0.6			0.7			0.2			NS			1.5			0.8	
CV%		14.6			12.9			15.9			8.6			4.9			5	

LSD: least significant difference; CV: coefficient of variation; NS: not significant at P≤0.05

Effect of intercropping on bean nodulation and yield

Intercropping with KCB and PAN 67 significantly increased the number of nodules per plant at 21 DAE in all sites. However, no significant differences in this parameter were noted at 50% flowering (Table 3). A significantly high number of nodules per plant were noted in the wetter Waruhiu site than in the drier Mwea and Machakos experimental sites. Low bean nodulation in semi-arid regions has been noted by many researchers (Hornetz *et al.,* 2001; Shisanya, 2002 and Mnasri *et al.,* 2007). High temperatures and water stress in dry areas could be inhibitory factors to establishment of rhizobia-legume symbiosis. Early maturing maize varieties could be less competitive than late maturity varieties for growth resources, which similarly influence rhizobia-legume symbiosis.

Table 3. Mean nodule count at 21 days after emergence (DAE) and at 50% flowering, seed yield and percent yield decline of KB 1 bean intercropped with sixteen maize varieties in Machakos, Mwea and Waruhiu during 2009 long rains.

Cropping System	Nodule Count at 21 DAE				Nodule Count at 50% Flowering				Seed Yield (kg ha-1)				Percent (%) Yield Decline			
	Mwea	Waruhiu	Machakos	Mean	Mwea	Waruhiu	Machakos	Mean	Mwea	Waruhiu	Machakos	Mean	Mwea	Waruhiu	Machakos	Mean
DHO 1 + beans	8.3	17.5	5.5	10.5	17.7	33.4	10.2	20.5	204	752	117	478	69.9	53.6	72.4	61.8
DHO 2 + beans	7.5	16.7	3.7	9.3	17.1	34.3	9	20.1	273	877	183	575	59.5	46.1	57.2	52.8
DHO 4 + beans	8.3	17.5	5.5	10.4	17.1	30.7	10.8	19.6	338	905	229	622	50	44.9	46.1	47.5
DK 8031 + beans	7.9	17.3	5.6	10.3	17.3	31.3	11.5	20.1	268	737	164	503	60.4	53.7	61.2	58.4
DUMA 43 + beans	8.5	17.8	6	10.7	17.6	33.8	11.1	20.9	219	649	247	434	67.5	60.3	41.5	56.4
H513 + beans	7.7	17.3	5.3	10.1	16.9	33.3	9.8	20.1	447	405	214	426	33.8	75.2	49.7	52.9
H515 + beans	6.6	14.9	3.9	8.5	15.2	31.9	9.3	18.8	225	647	134	436	66.7	60.8	68	65.2
H516 + beans	7.1	14.1	3.7	8.3	16.1	31.8	10.4	19.4	261	693	175	477	61.4	57.8	59.8	59.6
H614D + beans	6.5	13.9	3.6	8	15.5	30.8	8.7	18.7	288	1037	186	663	57.3	35	55.2	49.1
Katumani + beans	7.7	16.8	4.8	9.8	16	34.2	9.4	19.9	290	643	361	467	57.1	62	16.8	45.3
KCB + beans	8.4	19.7	5.2	11.1	18.5	35.4	9.4	21.1	256	1102	167	679	62.2	32.3	60.2	51.5
PAN 4M + beans	7.2	15.9	4.7	9.2	17	33.7	10.1	20.3	347	1023	196	685	48.6	39.7	52.4	46.9
PAN 67 + beans	9.4	17.2	6.1	10.9	18.1	35.4	10.1	21.2	248	794	270	521	63.5	53.5	50.1	55.7
PAN 77 + beans	7.5	17.7	4.8	10	17.3	33.5	9.1	19.9	221	592	109	407	67.4	65.5	73.7	68.8
PAN 7M + beans	7.6	15.8	4.2	9.2	16.6	31.6	9.8	19.3	307	887	93	597	54.3	45.4	77.9	59.2
PHB 3253 + beans	8.1	18.5	5.6	10.7	17.5	34.6	9.7	20.6	249	1026	196	638	63.1	37.6	54	51.5
KB 1 sole beans	6.1	16.4	4.6	9.1	16.9	34	7.8	19.6	676	1661	437	1169	-	-	-	-
Mean	7.7	16.8	4.9	9.8	17	33.2	9.8	20	301	849	205	575	58.9	51.5	56	55.4
LSD $_{(P\leq0.05)}$ CS	1.6				NS				144.6				11.8			
LSD $_{(P\leq0.05)}$ Site	0.6				0.8				60.7				5.1			
LSD $_{(P\leq0.05)}$ CS*Site	NS				NS				250.4				20.4			
CV %	17.8				10.3				34.2				22.7			

CS: cropping system; LSD: least significant difference; NS: not significant; CV: coefficient of variation.

Intercropping significantly (P≤0.05) depressed average bean seed yields by 58.92%, 56.01% and 51.46% in Mwea, Machakos and Waruhiu, respectively (Table 3). Significant yield declines of 75.2% and 77.9% were noted when KB 1 was intercropped with H513 in Waruhiu and Pannar 7M in Machakos. Yield reduction was related to reduced pods per plant and seeds per pod in the intercrop systems. Such significant yield declines have been reported before by researchers working in maize-bean intercrop systems (Tamado *et al.,* 2007; Gebeyehu *et al.*, 2006; Maingi *et al.*, 2000; Shisanya, 2003). Elsewhere, working under semi-arid conditions, Muraya *et al.*, 2006) obtained bean yield declines of between 48.3% and 77.2% in a maize-bean intercrop system. Competition for light is considered one of the major factors contributing towards reduction in growth and yield of crops in intercrop systems. Since bean yield tends to decrease with decrease in light transmission, it can be inferred that the yield of beans were reduced because of shading. Kinama *et al.*, 2007, showed that intercropping cowpea with maize in semi-arid Kenya reduced cowpea yield due to shading effects. Bean yield reduction could have also been due to inter-specific competition for resources such as nutrients and water (Zhang and Li, 2003).

Table 4. Mean Land Equivalent Ratio and Monetary Advantage Index (Kshs) of intercropping KB 1 bean with sixteen maize varieties in Mwea and Waruhiu during 2009 long rains.

Cropping System (CS)	Land Equivalent Ratio			Monetary Advantage Index		
	Mwea	Waruhiu	Mean	Mwea	Waruhiu	Mean
DHO 1 + Beans	1.2	1.5	1.4	9,861	28,374	19,118
DHO 2 + Beans	1.4	1.7	1.6	17,712	33,192	25,452
DHO 4 + Beans	1.4	1.5	1.5	23,771	26,585	25,178
DK 8031 + Beans	1.3	1.3	1.3	20,923	21,227	21,075
DUMA 43 + Beans	1.5	1.3	1.4	18,667	17,290	17,979
H513 + Beans	1.8	1.4	1.6	27,950	21,664	24,807
H515 + Beans	1.1	1.5	1.4	5,745	25,094	15,420
H516 + Beans	1.3	1.5	1.5	15,065	25,901	20,483
H614D + Beans	1.3	1.7	1.5	12,677	31,035	21,856
Katumani + Beans	1.4	1.2	1.3	13,234	23,699	18,467
KCB + Beans	1.5	1.5	1.5	15,540	28,789	22,165
PANNAR 4M + Beans	1.4	1.8	1.6	17,461	36,701	27,081
PANNAR 67 + Beans	1.4	1.9	1.6	15,892	43,326	29,609
PANNAR 77 + Beans	1.3	1.5	1.4	12,794	22,659	17,727
PANNAR 7M + Beans	1.5	1.5	1.5	15,467	36,912	26,190
PHB 3253 + Beans	1.4	1.9	1.6	19,994	38,173	29,084
Mean	1.4	1.5	1.5	16,422	28,788	22,605
LSD $_{(P\leq0.05)}$ CS		NS			NS	
LSD $_{(P\leq0.05)}$ Site		0.1			5047	
LSD $_{(P\leq0.05)}$ CS*Site		NS			NS	
CV %		22.5			54.7	

LSD: least significant difference; NS: not significant at ($P\leq0.05$); CV: coefficient of variation

Productivity and monetary value of maize-bean intercrop systems

Intercropping KB 1 with the maize varieties increased grain production and monetary value per unit area (Table 4). Intercropping yield advantages ranged from 16% for H515/KB 1 intercrop to 84% for H513/KB 1 intercrop in Mwea while in Waruhiu yield advantages ranged from 41% for H513/KB 1 intercrop to 92% for Pannar 67/KB 1 intercrop. Significantly higher yield advantages were obtained in Waruhiu than in Mwea. In Mwea the LER revealed that it would require 1.16 to 1.84 more units land with farmers who practice sole cropping of maize and beans to produce comparable yield to intercropping KB 1 bean variety with maize. Similarly in Waruhiu, it would require on average 1.57 more units of land of maize and bean monocultures to produce comparable yield in maize/bean intercrop system. Again in Table 4, monetary advantage for intercropping was not significantly ($P\leq0.05$) affected by maize variety in maize/bean intercrop systems. However, numerically higher returns of Kshs. 23, 771 for DHO 4/KB 1 intercrop and Kshs. 43, 326 for Pannar

67/KB 1 intercrop system were obtained in Mwea and Waruhiu respectively. Since all intercrop systems had LER > 1, this indicates that intercropping was superior to sole-cropping. However, lack of significant differences among the intercrop systems, is in line swith studies by Tamado *et al.*, 2007, Yilmaz *et al.*, 2007, Mbah *et al.*, 2007, Tsubo *et al.*, 2003 and Rahman, *et al.*, 2009. The yield advantage from such intercropping can be attributed to optimized utilization of solar radiation, soil water and nutrients, and growth space among other above and below ground resources (Tsubo *et al.,* 2003).

Conclusion and recommendations

Performance of the currently grown varieties in the semi-arid regions depends on the amount of rainfall received during the growing season. Composites Katumani and KCB, DHO 1 and DHO 2 showed consistency in early maturity. These varieties can be adopted in the semi-arid regions if they are planted early in the growing season to optimize use of available resources especially soil moisture. Among the dryland hybrids (DHO series), variety DHO 4 may not be recommended for the semi-arid regions due its significantly long maturity duration. Variety H614D which is a late maturing variety may not be recommended for cultivation in semi-arid regions. Variety PHB 3253 may be preferred in these regions due to its high yield potential, a trait shown by its significantly high number of kernel-rows per cob. Perhaps, this variety may be widely grown incases where the growing season has been predicted to meet the optimal growth conditions for maize. Further, this study found that in a maize/bean intercrop system, the bean component does not significantly affect maize grain yield and yield components. However, the maize component significantly affects beans performance by depressing the bean yields. The choice of a compatible maize variety is thus essential to maximize bean productivity.

To optimize the ecological and economic benefits of maize/bean intercrop in terms of yield, variety selection and compatibility of the component crops should be made using established agronomic management practices involving the two crops. Suitable maize varieties for maize/bean intercrop systems are varieties that have less dense canopy. These varieties would therefore have lesser shading effect to the understory beans. However, establishment of an appropriate spatial arrangement of the component crops would be essential to alleviate negative effects especially on the less competitive crop. Therefore, this study concludes that to improve maize grain food security and enhance productivity of maize-bean intercrops in semi-arid regions, varieties Katumani, KCB, DHO 1 and DHO 2 may be adopted. Earliness of these varieties is a key trait for drought tolerance. Additionally, their high harvest index is an indication of their efficiency in translocating carbohydrates to the grain.

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