EARLY ASSESSMENT OF GROWTH AND YIELD CHARACTERS OF FIVE NEWLY DEVELOPED LINES OF ARABICA COFFEE IN TWO ENVIRONMENTS AND SPACINGS IN KENYA

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ABSTRACT

Knowledge of the effects of environment and genotype by environment (GxE) interaction is important to breeders in making decisions regarding the release of new cultivars. Five *Coffea arabica* lines coded CR8, CR22, CR23, CR27 and CR30 have been developed by Coffee Research Foundation and are currently being tested for release in various coffee growing zones in Kenya. The objective of this study was to determine the performance of the five advanced breeders' lines under varying environment and spacing. Two commercial Arabica cultivars, SL28 and Ruiru 11 were included in the study as check cultivars. The trial was established during the long rain season of March/April 2007 at Kitale in Western Kenya and Meru in Eastern Kenya. The experiment was laid out in a Randomized Complete Block Design (RCBD) with 10 trees per plot planted at spacing of 2 m x 1.5 m and 2.75 m x 2.75m and replicated three times. Growth and yield data were recorded at the end of the first and second year after field establishment. The data were subjected to analysis of variance. Duncans Multiple Range Test (DMRT) was used to separate significantly different means at P = 0.05. Data were further subjected to cluster and principle component analyses. Significant environment effect was observed on all variables. Closer spacing promoted better expression of the variables than wider spacing, except for length of the longest primary and internode length. The years were also significantly (P<0.05) different with all parameters being more pronounced in the second year (2009) than in first year (2008), except the internode length on primaries where the case was vice versa. Correlation between the main growth characters and yield characters was significant (P<0.0001). The study confirmed that the new lines were better or similar to existing varieties and therefore the breeding objective was achieved. Lack of genotype by environment interaction indicated the stability of the genotypes.

Key words: *Coffea arabica*, Genotype, Environment, Kitale, Meru

INTRODUCTION

Coffee production is fundamental for over 50 developing countries, for which it is the main foreign currency earner (Agwanda *et al*., 1997). French

Missionaries introduced coffee to Kenya around 1900 AD (Mwangi, 1983) and since then, it has been an important player in the country's economy (Condliffe *et al*., 2008). It contributes upto 20% of the total hard currency revenue in Kenya. It is estimated that out of the 70% of Kenya's workforce engaged in agriculture, 30% are employed in the coffee industry (Omondi et al., 2001). Performance of coffee in Kenya has been declining as evident from the drop in coffee exports, quality and yields (Condliffe *et al*., 2008).

Over 90% of the total Kenyan coffee acreage is under arabica coffee (*Coffea arabica* L.), while the rest is occupied by Robusta coffee (*C. canephora* Pierri). The duration of a breeding programme in arabica coffee to produce new cultivars resistant to important diseases, such as coffee leaf rust and berry disease, largely depends on the efficiency of selection for yield since methods of early selection for disease resistance are already available (Walyaro and Van der Vossen, 1979).

For most crop species, successful cultivars must be adapted to a wide range of climatic and soil conditions. For arabica coffee, these conditions may range from the semi-arid and low altitude conditions in parts of the Eastern Province, to the proportionately higher rainfall highlands of Kenya. In these regions, crop yields fluctuate by year and by location (Wamatu *et al*., 2003). The growing environment also has a strong effect on the expression of quality parameters exhibited by the cultivars Ruiru 11 and SL28 (Omondi, 2008). The main coffee growing areas in Kenya are in three altitude zones; the high altitude (over 1700 m above sea level), the medium altitude (between 1580 m and 1760 m above sea level) and the low altitude (1200 m –1580 m above sea level) (Mwangi, 1983). However, production across theses climatic ranges is seriously constrained by diseases, especially coffee berry disease caused by *Colletotrichum kahawae* and coffee leaf rust caused by *Hemileia vastatrix*. (Omondi *et al*., 2001). Chemical control by use of fungicides is expensive and may account for upto 30% of the production costs (Gichuru *et al*., 2008). An economical and sustainable control can be achieved by growing resistant cultivars (Omondi *et al*., 2001) that reduce the costs of chemical control and are safe to humans and the environment (Gichuru *et al*., 2008).

Much of the world coffee is still produced by traditional cultivars of *Coffea arabica* (66%) and *Coffea canephora* (34%), released some 50 to 80 years ago from relatively simple selection and breeding programmes and generally multiplied by seed (Van der Vossen, 2009). Traditional varieties of *Coffea arabica* that are still in production in Kenya include K7 that is recommended for low altitude areas, SL28 for low to medium altitudes, and SL34 for medium to high altitudes (Mwangi, 1983). These traditional cultivars, are susceptible to

coffee leaf rust and coffee berry disease (Van der Vossen, 2009). New arabica cultivars with high yield potential and resistance to the two diseases have started to replace the traditional varieties on a large scale in several countries (Van der Vossen, 2001). An Arabica coffee cultivar, Ruiru 11, developed at the Coffee Research Station, Ruiru, Kenya, and released to growers in 1985, combines resistance to CBD and leaf rust with high yield, fine quality and compact growth amenable to high density planting (Omondi *et al.*, 2001). However, it is believed that Ruiru 11 being a compact variety, the root system may be relatively shallow compared to the tall, traditional varieties and therefore it is not suitable for marginal areas with inadequate rainfall.

Coffee Research Foundation has recently developed five new lines code-named CR8, CR22, CR23, CR27 and CR30 that are currently being tested for release. The five lines were selected at Coffee Research Station in Ruiru as individual tree selections from backcross progenies involving SL4, N39, Hibrido de Timor and Rume Sudan as the donor varieties and the traditional commercial cultivars SL28, SL34 and K7 as the recurrent parents. Their unique features include tall stature, true-breeding and resistance to coffee berry disease and coffee leaf rust. They are also high yielding with good bean and liquor quality comparable to that of Ruiru 11 and SL28. The objective of this study was to determine the performance of the five breeder's lines under varying environments, production seasons and spacing relative to that of the existing commercial cultivars in Kenya.

MATERIALS AND METHODS
Study Sites
The study was carried out at Coffee Research Foundation sub-stations at Kitale in Western Kenya and at Meru (Mariene) in Eastern Kenya. Kitale coffee sub-station is located within upper midland 2 agro-ecological zone with rainfall above 1000 mm annually. The soils are well drained, fairy deep sandy clays to loamy clays and full weatherable minerals (Mburu *et al.*, 2005).

Mariene sub-station lies in Upper Midland 1 agro-ecological zone at an altitude of 1524 m asl. It receives an average annual rainfall of 1979 mm with 60% reliability. The soils are classified as ando-humic nitosols. They are well drained, extremely deep, dark-reddish brown to dark-brown, friable and slightly smeary clay, with acid humic topsoil (Jaetzold and Schmidt, 1983). The trial was established during the long rain season of March/April 2007.

Test Materials
The test materials included five advanced breeders' lines code-named CR8, CR22, CR23, CR27 and CR30 which were evaluated alongside two

commercial Arabica cultivars, SL28 and Ruiru 11 as check cultivars. The five breeder's lines have been developed by Coffee Research Foundation in Ruiru, Kenya. They are true-breeding with tall stature and have been tested both in the laboratory and in the field and proven to be resistant to coffee berry disease and coffee leaf rust. They are also high yielding with good bean and liquor quality comparable to that of Ruiru 11 and SL28.

Experimental Layout
The experiments were laid out in a randomized complete block design with 10 trees per plot replicated three times. The trees were planted at two spacings of 2 m x 1.5 m and 2.75 m x 2.75 m. The plots were surrounded by a guard row of SL28. All management practices were carried out in similar manner.

Data Collection
Growth and yield characters were recorded at the end of the first and the second year after field establishment. Variables measured included girth, height, number of nodes on the main stem, internode length on the main stem, number of primaries, number of bearing primaries, percent bearing primaries, longest primary, nodes on longest primary, internode length on longest primary, nodes on bearing primary, bearing nodes, percent bearing nodes, and berries per node.

Data Analysis
Data were subjected to analysis of variance using COSTAT software and effects declared significant at 5% level. A combined analysis of variance was performed on data from both sites. Duncans Multiple Range Test was used to separate significantly different means. Linear correlation was done to compare the association between main growth characters and yield characters. In order to illustrate the location and spacing effect, the data was organized into a matrix and subjected to cluster analysis using R Statistical Software (Venables *et al*., 2006) and a dendrogram constructed using the unweighted pair-group method with arithmetic average [UPGMA]. The SAS procedure PRINCOMP was then used to perform a principle component (PC) analysis using SAS version 9.1 and the genotypes plotted on two dimensions using the first two principle components (PC1 and PC2). This plotting was done to illustrate variation in genotypes and to obtain the principle component of variation.

RESULTS
The growth and yield characters for the five advanced breeders' lines were better or similar to those of the traditional variety SL28 and improved cultivar Ruiru 11 (Table 1). Ruiru 11 was significantly (P<0.05) different from the rest in girth, height, internode length on the main stem (IL), total

number of primaries (P), length of the longest primary (LP) and internode length on longest primary (ILP) (Table 1). There was a significant (P<0.05) environment effect for all parameters that were measured (Table 2). Spacing had a significant (P<0.05) effect on height, number of nodes on the main stem (N), total number of primaries (P), internode length on the longest primary (ILP) and number of laterals (L) (Table 2). Closer spacing promoted better expression of the parameters than wider spacing, except for length of the longest primary (LP) and internode length on the longest primary (ILP). The years were also significantly (P<0.05) different with all parameters being more pronounced in the second year (2009) than in first year (2008) except the internode length on primaries (ILP) where the case was vice versa (Table 2). There was significant (P<0.0001) correlation between the main growth characters and yield characters as shown in Table 3.

Results of the cluster analysis are presented in Figure 1. The genotypes were clustered into three supported clusters (C1, C2 and C3). Environment effect was better illustrated by the cluster dendrogram where the two sites separated clearly into two main clusters (Figure 1), except the cultivar Ruiru 11 in Meru, which clustered with the other cultivars in Kitale in the main cluster, but separated to its own sub-cluster between the two sites. Spacing effect was least in Ruiru 11 as it is the only genotype whose representatives for both spacings in Meru and Kitale clustered together.

The Principle Component Analysis (PCA) detected significant variations between genotypes as illustrated in Figure 2a. One of the new lines coded CR8 and the improved cultivar Ruiru 11 were placed on the upper part of the PCA graph. The two recorded significantly high in most of the yield parameters (Table 2) which contributed most to PC1 and least to PC2 (Table 4). However, Ruiru 11 was a bit inferior in terms of growth characters, which contributed most to PC2 (Table 4), thus placing it on the left side of the PCA graph (Figure 2a). The rest of the genotypes were placed on the lower part of the PCA graph with CR22, CR23, CR27 and SL28 being grouped close together. CR30 performed poorly in yield characters and was placed at the very bottom. Just like cluster analysis, PCA did not detect any genotype by environment interaction. The genotypes separated into two groups (Figure 2b), but representatives of every genotype for both sites (Meru and Kitale) were grouped together.

Table 1. Mean growth variables for both sites combined

| Variety	Girth	Height	N	IL	P	BP	%BP	LP	NLP	ILP	NBP	%BN	L	Berries	B/N	NMB
CR8	9.48a	102.64ab	23.33a	4.29b	33.74a	13.03a	28.34a	54.55ab	17.24ab	3.22ab	4.84a	21.20a	2.27ab	4.15a	2.08a	2.08a
CR22	8.94b	99.87b	21.71b	4.46ab	31.18c	10.79b	24.57b	50.68c	15.91c	3.20ab	3.99bc	18.57ab	2.01c	3.64b	1.92abc	3.75b
CR23	9.45a	105.49a	22.87a	4.49ab	33.11ab	11.00b	24.69b	55.40a	17.10ab	3.25ab	4.11bc	18.50ab	2.31a	3.82ab	2.04ab	3.76b
CR27	9.21ab	100.51ab	21.10b	4.59a	30.46c	9.96b	23.10b	55.69a	16.65abc	3.35a	4.12bc	18.53ab	1.99c	3.65b	1.75cd	3.77b
CR30	9.19ab	97.98b	22.00b	4.35ab	31.81bc	9.88b	22.36b	52.10bc	16.25bc	3.17b	3.54c	16.26b	2.11bc	3.13c	1.64d	3.20b
SL28	9.12ab	99.06b	21.51b	4.49ab	30.90c	9.65b	22.00b	55.49a	16.91ab	3.29ab	3.84c	16.30b	2.10bc	3.47bc	1.64d	3.84b
Ruiru 11	8.25c	70.81c	21.34b	3.28c	31.55c	11.13b	24.98b	47.35d	17.49a	2.71c	4.55ab	18.83ab	2.23ab	3.79ab	1.85bcd	3.84b
Min CR	0.3925	5.0460	0.8409	0.2250	1.4020	1.3180	2.8330	2.6360	0.9050	0.1567	0.5710	2.7450	0.1820	0.3622	0.2044	0.6456
CV%	7.5458	9.1284	6.6870	9.1909	7.7042	21.3854	20.3836	8.6875	9.4189	8.6424	24.1006	26.1987	14.8094	17.2878	19.3554	29.5286

Key: N= Number of nodes on the main stem, IL= Internode length on the main stem, P= Number of primaries, BP= Bearing primaries, LP= Longest primary, NLP= Nodes on longest primary, ILP= Internode length on longest primary, NBP= Nodes on bearing primaries, BN= Bearing nodes, L= Number of Laterals, B/N= Berries per node, NHB= Node with most berries, Min CR = Minimum Critical Range of DMRT (equivalent to LSD), CV = Coefficient of variation.

Table 2. Location, spacing and seasonal variations

Variable		Girth	Height	N	IL	P	BP	%BP	LP	NLP	ILP	NBP	%BN	L	Berries	B/N	NMB
Site	Meru	10.72a	120.08a	23.09a	5.12a	36.19a	13.08a	26.68a	66.88a	18.20a	3.77a	5.34a	22.43a	2.31a	4.55a	2.24a	5.24a
	Kitale	7.46b	73.16b	20.87b	3.44b	27.45b	8.47b	21.91b	39.20b	15.39b	2.57b	2.94b	14.20b	1.99b	2.77b	1.45b	2.41b
Spacing (m)	2.0x1.5	9.16a	99.40a	22.51a	4.30a	33.17a	10.99a	24.99a	52.96a	16.99a	3.12b	4.25a	18.53a	2.25a	3.72a	1.85a	3.95a
	2.75x2.75	9.02a	93.84b	21.45b	4.26a	30.47b	10.56a	23.59a	53.11a	16.60a	3.21a	4.03a	18.09a	2.05b	3.60a	1.84a	3.70a
Season	2009	12.11a	128.80a	27.34a	4.69a	44.96a	21.03a	46.13a	71.49a	23.08a	3.10b	8.00a	34.19a	2.85a	6.31a	2.42a	7.34a
	2008	6.07b	64.44b	16.62b	3.87b	18.68b	0.52b	2.46b	34.58b	10.51b	3.24a	0.28b	2.44b	1.44b	1.02b	1.27b	0.31b
Critical range		0.210	2.697	0.450	0.120	0.750	0.705	1.514	1.409	0.484	0.084	0.305	1.467	0.097	0.194	0.109	0.345

**Table 3. Linear correlation between some growth and yield characters**

	Primaries	BP	%BP	LP	NLP	NBP	%BN	B/N	Berries
Nodes	0.968 **	0.953**	0.916**	0.849**	0.953 **	0.937**	0.917**	0.775**	0.871**
Primaries		0.970**	0.929**	0.912**	0.966 **	0.954**	0.940**	0.817**	0.882**
BP			0.822**	0.880**	0.857**	0.948**	0.914**	0.801**	0.888**
%BP				0.819**	0.948**	0.924**	0.936**	0.767**	0.822**
LP					0.877**	0.894**	0.872**	0.868**	0.880**
NLP						0.944**	0.928**	0.788**	0.857**
NBP							0.985**	0.846**	0.948**
%BN								0.843**	0.914**
B/N									0.886**

Key: ** = P<0.0001, BP= Bearing Primaries, LP= Longest Primary, NLP= Nodes on Longest Primary, NBP= Nodes on bearing primaries, BN= Bearing Nodes, B/N= Berries per Node
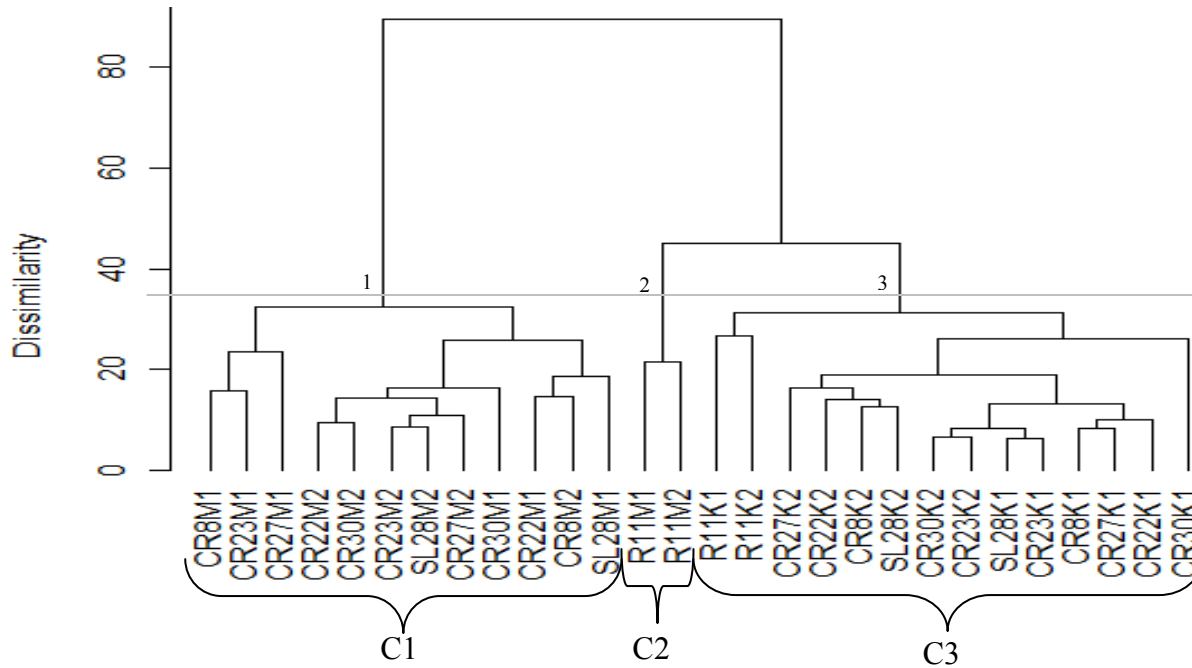
Figure 1: Cluster dendrogram illustrating diversity among genotypes location and spacing effect. The letters M and K added at the end of genotype code represents Meru and Kitale respectively while the numbers represents different spacings
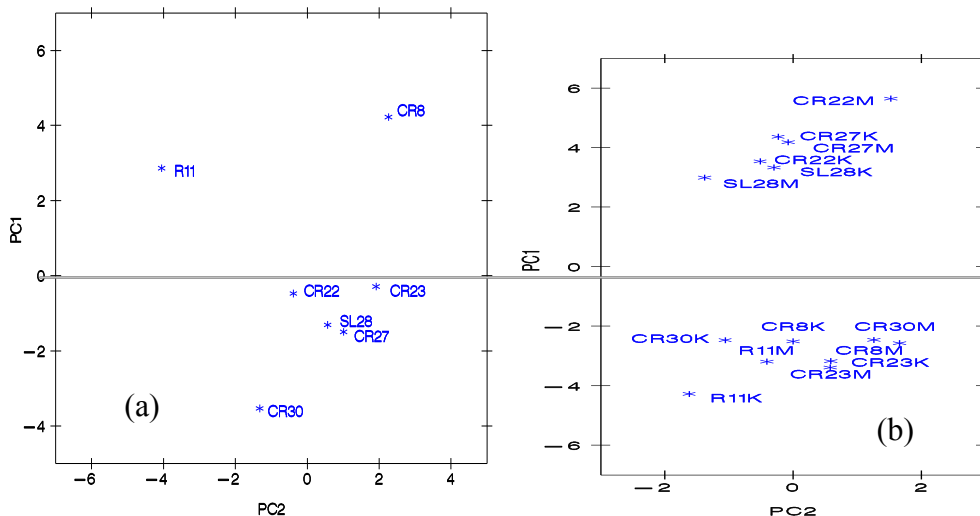
Figure 2: Principle Component Analysis plots illustrating variation among genotypes. Graph (a) has both sites combined while graph (b) has the sites separated. M and K at the end

Table 4. The first two principle components of various growth and yield characters

Parameter	Combined sites		Separate sites	
	PC1	PC2	PC1	PC2
Girth	-.101592	0.420733	0.263963	-.112297
Height	-.136598	0.415891	0.262928	-.159654
Nodes on Main Stem	0.247962	0.184637	0.191292	0.324663
Internode Length	-.226713	0.341844	0.243520	-.359434
Primaries	0.256996	0.169048	0.264829	0.106678
Bearing Primaries	0.341157	0.083801	0.257730	0.279670
% Bearing Primaries	0.346991	0.006325	0.216282	0.486209
Longest Primary	-.139412	0.394637	0.263969	-.144638
Nodes on Longest Primaries	0.293359	0.019561	0.259618	0.078982
Internode length on longest primary	-.266397	0.318305	0.255521	-.249897
Nodes on bearing primaries	0.354659	0.007832	0.261871	0.057024
% Bearing Nodes	0.071913	-.157335	0.252211	0.009504
Number of Laterals	0.219334	0.246858	-.188438	0.537894
Total number of Berries	0.305916	0.180157	0.265838	0.111359
Berries per Node	0.149178	0.219511	0.263675	0.025997
Node with Most Berries	0.289715	0.198986	0.267766	0.077139
Eigen value	7.1263	4.7380	13.5533	1.0432
Proportion	0.4454	0.2961	0.8471	0.0652
Cumulative	0.4454	0.7415	0.8471	0.9123

The total number of berries was used as the most direct measure of the yield potential and the entire performance of the test materials. Analysis of the total number of berries (Table 5) detected highly significant (P<0.0001) variation among genotypes as well as highly significant (P<0.0001) effect due to the growing environment (site) and year. Site x spacing and site x year interactions were also highly significant (P<0.0001). However, genotype x site (environment) interactions were not significant (P>0.05).

Table 5. Analysis of variance results for total number of berries

Source	DF	SS	MSE	F Value	Pr > F
Site	1	132.264	132.264	329.98	<.0001
Genotype	6	14.4978	2.4163	6.03	<.0001
Spacing	1	0.5796	0.5796	1.45	0.2318
Year	1	1176.42	1176.42	2935	<.0001
Genotype x Site (G x E)	6	4.2694	0.7116	1.78	0.1107
Genotype x Spacing	6	3.1136	0.5189	1.29	0.2656
Genotype x Year	6	7.4116	1.2353	3.08	0.0079
Site x Spacing	1	13.0973	13.0973	32.68	<.0001
Site x Year	1	46.7572	46.7572	116.65	<.0001
Spacing x Year	1	0.0125	0.0125	0.03	0.8603
Site x G x S x Y	25	23.7044	0.9482	2.37	0.0012
Rep	2	1.9658	0.9829	2.45	0.0908
Error	110	44.0908	0.4008		
Corrected Total	167	1468.19			

DISCUSSION

The main breeding goal in the development of the five new lines was to increase coffee production and returns in Kenya. Selection criteria was therefore targeted to come up with a variety that is suitable for all coffee growing areas in Kenya unlike the existing cultivars that are suited for defined agroecological zones (Mwangi, 1983). Although the improved cultivar, Ruiru 11 combines disease resistance with good quality and high yields (Omondi *et al.*, 2001), the cultivar is reportedly unsuitable for marginal areas due to its relatively shallow root system. On the other hand, the high yielding traditional varieties such as SL28 are recommended for low to medium altitudes (Mwangi, 1983) as they are susceptible to coffee leaf rust and coffee berry disease (Van der Vossen, 2009).

In this study, the breeders' lines were better or similar to the two existing commercial cultivars in yield and growth characters. The improved cultivar Ruiru 11 was significantly shorter and compact than the rest but similar or better in yield characters. It inherited the trait for compactness from the

variety Catimor and has proved to be high yielding and of fine quality comparable to the traditional variety, SL28 (Omondi *et al.*, 2001). The highly significant correlation between the total number of berries and the main growth and yield characters indicated that early growth recording can be used to measure the yield potential of the materials being tested. Correlation between the total number of berries and the bearing primaries (89%) was slightly higher than that between the total number of berries and percent bearing primaries (82%). The 7% difference indicated that some if not all the trees had not attained their maximum bearing capacity at the time the data was taken. Field observation has shown that CR8 is relatively early bearing while CR30 is late bearing. A similar trend was observed for nodes on bearing primaries (95%) and percent bearing nodes (91%). Proper timing is therefore important if reliable data is to be taken; otherwise the information can be deceptive.

The growing environment had a significant effect on all the genotypes. Both growth and yield characters were better expressed in Meru than in Kitale. This observation was attributed to the different cropping conditions at Meru and Kitale. Meru has two cropping seasons with main flowering in October/November, while Kitale has one main flowering in March/April. The observation was also be attributed to different climatic and edaphic conditions between the two locations. Wamatu *et al*. (2003), reported that within the coffee growing regions, crop yields fluctuate from location to location. The results, however, showed that both the existing varieties and the new lines were affected almost equally by change of environment. This was confirmed by lack of significant genotype by environment (G x E) interactions. This result was a positive observation for the new lines, indicating that the lines were stable and suitable for wide adaptation rather than specific adaptation.

Closer spacing promoted better expression of most of the parameters than wider spacing. This was attributed to better utilization of nutrients applied per unit area in closer spacing than in wider spacing, as well as competition to the sunlight which causes elongation of plants. Wider spacing promoted lateral growth as it recorded the longest primary with the longest internode length. From the cluster analysis results, it was clear that Ruiru 11 was the least affected by spacing and this was attributed to its dwarf compact stature emanating from its short internodes on both main stem and branch (Nyoro and Sprey, 1986). From this study, it appeared that two years data is not enough to express fully the effect of spacing probably because there is little or no competition for major resources such as water, light and nutrients. However, yield per unit land is expected to increase to a certain extent under

close spacing and more research is necessary to determine the spacing that could give optimal returns. Genotype by spacing interaction was not significant, indicating that all the genotypes were being affected almost equally by spacing.

As expected, all parameters were more pronounced in the second year (2009) than in first year (2008), except internode length on primaries. The latter can be explained by the fact that as growth continues, more but shorter nodes are formed. For newly established coffee plants, when all the other variables are held constant, growth and yield characters are expected to increase almost exponentially up to a certain threshold above which the limits are determined by the management practices applied. However, for established coffee trees, biennial bearing phenomenon is common and Wamatu *et al*. (2003) reported that coffee yields fluctuates from year to year. The early years of growth can therefore be used to measure the yield potential of the materials being tested. Walyaro and Van der Vossen (1979) reported the possibility of early selection for yield potential enabled by the presence of significant phenotypic correlation between the first 2-3 years and the total 5-6 years of production and between plant vigour and yield.

CONCLUSION
The study confirmed that the new lines were better or similar to existing varieties in all the characters that were measured and therefore the breeding objective was achieved. Lack of genotype by environment interaction was an indication of the stability of the genotypes which is also a positive observation. Two years data is not enough to express fully the effect of spacing as there is little competition for major resources such as water, light and nutrients in the early years of production. However, since yield per unit land is expected to increase to a certain extent with closer spacing, this research should be carried on for several more years to determine the spacing that could give optimal returns. Further research with more varying spacing is also needed. This study confirmed that early growth recording can be used to measure the yield potential of the materials being tested. However, differences between correlation coefficients of the major bearing points (primaries and nodes) and the ratio of the total bearing points to actual bearing points is indicative of the importance of proper timing of data recording to ensure that the data is reliable and not misleading.

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REFERENCES

Agwanda, C.O., Lashermes, P., Trouslot, P., Combes, M. and Charrier, A. 1997. Identification of RAPD markers for resistance to coffee berry disease, Colletotrichum kahawae, in arabica coffee. Euphytica 97:241–248, 1997. 241

Condliffe, K., Kebuchi, W., Love, C. and Ruparell, R. (2008). Kenya Coffee: A Cluster Analysis. In: Professor Michael Porter, Microeconomics of Competitiveness. Harvard Business School, May 2, 2008. Pp. 2

Gichuru, E.K., Agwanda, C.O., Combes, M.C., Mutitu, E.W., Ngugi, E.C.K., Bertrand, B. and Lashermes, P. (2008). Identification of molecular markers linked to a gene conferring resistance to coffee berry disease (*Colletotrichum kahawae*) in C*offea arabica* Plant Pathology 57:1117–1124

Jaetzold, R. and Schmidt, H. (1983). Farm Managenent Handbook of Kenya. Vol. II, Natural Conditions and Farm Management Information, Part A, West Kenya (Nyanza and Western Provinces). Government of Kenya, pp. 8183, 100-101.

Mburu, J.N., Mugo, H.M. and Waweru, P.R. (2005). Sub-stations and Demonstration Plot Technical Reports. Coffee Research Foundation.

Mwangi, C.N. (1983). Coffee growers' handbook. Coffee Research Foundation, Kenya. pp. 128

Nyoro J.K. and Sprey L.H. (1986). Introducing Ruiru 11 to the Estates and Small Holders. Kenya Coffee Vol. 51 No. 592 pp. 9

Omondi, C.O. (2008). Coffee quality assessment: the case of two Kenyan cultivars, Ruiru 11 and SL28. In *Proceedings of the 22nd ASIC International Coffee Conference, Campinas, Brasil, Lausanne, Switzerland*, 1307–1311

Omondi C.O., Ayiecho P.O., Mwang'ombe A.W. and Hindorf H. (2001). Resistance of *Coffea arabica* cv. Ruiru 11 tested with different isolates of *Colletotrichum kahawae*, the causal agent of coffee berry disease *Euphytica* 121: 19–24, Kluwer Academic Publishers, The Netherlands.

Opile W.R. and Agwanda C.O. (1993). Propagation and distribution of cultivar Ruiru 11: A review. Kenya Coffee 58: 1496-1508.

Van der Vossen H.A.M. (2009). The Cup Quality of Disease-Resistant Cultivars of Arabica Coffee (*Coffea arabica*). *Experimental Agriculture* (2009), 45:323-332 Cambridge University Press.

Van der Vossen H.A.M. (2001). Coffee Breeding and Selection: Review of Achievements and Challenges. Proceedings of *19th International Colloquium* Association for Science and Information on Coffee, Trieste, Italy, 14-18 May 2001.

Venables, W.N., D.M. Smith and R Development Core Team (2006). An introduction to R: A programming environment for data analysis and graphics. Version 2.5.1. Online publication: <http://www.r-project.org>

Walyaro D.J. and Van der Vossen H.A.M. (1979). Early Determination of Yield Potential in Arabica Coffee by Applying Index Selection. Euphytica 28 465-472

Walyaro D.J. 1983. Considerations in breeding for improved yield and quality in arabica coffee *(Coffea arabica* L.). Doctoral Thesis. University of Wageningen, The Netherlands.

Wamatu J.N., Thomas E. and Piepho H.P. (2003). Responses of different arabica coffee (*Coffea arabica L.*) clones to varied environmental conditions. *Euphytica* 129: 175–182. Kluwer Academic Publishers. Printed in the Netherlands.