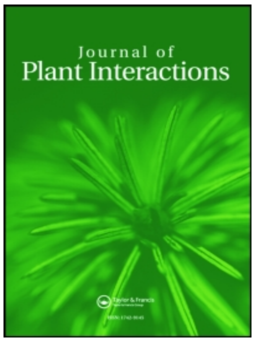

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Existing competitive indices in the intercropping system of *Manihot esculenta* Crantz and *Lagenaria siceraria* (Molina) Standley

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ABSTRACT
An assessment of the competitive indices in intercropping between cassava (*Manihot esculenta*) and bottle gourd (*Lagenaria siceraria*) was conducted with the aim of increasing the productivity of these crops. For this purpose, three farmers preferred landraces of cassava (*yacé*, *blêbou* and *six mois*) and three morphotypes of gourd (dark green and round fruit, light green and round fruit, light green and long fruit) were used to test the three intercropping ratios (gourd:cassava with 6:42, 6:24 and 6:18). Intercropping systems were assessed by land equivalent ratio (LER), area time equivalent ratio (ATER), relative crowding coefficient (*K*), actual yield loss (AYL), aggressivity (*A*) and competition ratio (CR). LER, ATER and *K* values were greater than 1 for gourd-cassava (6:24). These findings indicate an advantage of intercropping for exploiting the resources of the environment. Cassava clones were more competitive than gourd component.

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Lagenaria siceraria; *Manihot esculenta*; intercropping; competitive indices; additive experiments

Introduction

The development of cropping system adapted to climate change and meeting the nutritional and economic requirements of the local populations is a major challenge for scientists, political decision-makers and the organisms of development aid. In this context, promotion of plants and local cropping system firmly rooted in food and social habit of populations is recommended (Altieri 1999). Intercropping systems for sustainable tropical agriculture should be involved in such systems. This system is expected to withstand a wide range of ecological and climatic factors.

In the context of the reduction of cultivable lands, it is fundamental to achieve sustainable intercropping systems, thereby optimizing the efficient utilization of available growth resources (Hauggaard-Nielsen et al. 2001). The success of such investigations is strongly linked to several factors, among which crop husbandry and varieties or cultivars are the prerequisites. Cassava (*Manihot esculenta* Crantz) and bottle gourd (*Lagenaria siceraria* [Molina] Standley) are excellent plant models for intercropping in tropical region (Enete 2009). In fact, cassava is the third most important tropical crop after rice and maize, providing livelihoods and food security for hundreds of millions of people throughout the world (Hyman et al. 2012; Howeler et al. 2013). The bottle gourd has a wide morphological diversity and geographic distribution in the tropical world (Achigan et al. 2006). Seeds of this indigenous cucurbit have a very good market value ($ 2.5/kg) due to their cultural and culinary importance in the countries where they are cultivated (Zoro Bi et al. 2003; Zoro Bi et al. 2006). The seeds of *L. siceraria* exhibit the high macronutrient level and contain 34% proteins and 50% fat (Achu et al. 2005). These seeds can thus be considered as sources of proteins and oils to the smallholder farmers. A part from these economic, nutritional and cultural roles, bottle gourd serves as living mulch against weeds (Mandumbu & Karavina 2012) and therefore reduces the time devoted by farmer to weeding. In addition, cropping this species represents a reliable solution against soil erosion. An optimized mixed-cropping system involving cassava and bottle gourd should be an efficient approach to solve the problem of food and economic needs of an important part of populations from the tropical world.

Intercropping of cassava with legumes has been popular in tropical environments (Mbah et al. 2008; Ijoyah et al. 2012; Hidoto & Loha 2013). In these investigations, researchers have paid attention mainly to the biological yields without taking into account the interaction between the species intercropped (Jamshidi, 2011; Mbah & Ogidi 2012; Biareh et al. 2013; Nyi et al. 2014; Adeniyan et al. 2014). However, it is well established that different species growing together in the same place compete for nutrients, water and light (Ghosh 2004).

Several factors can affect the growth and yield of the species in mixture, particularly planting ratio, spatial arrangement, plant density, cultivar and competition between mixture components (Caballero et al. 1995; Dhima et al. 2007; Rezaei-Chianeh et al. 2011). Competition is one of the main factors having significant impact on growth rate and yield of plant species used in intercropping, compared with pure stands (Caballero et al. 1995). High yields are achieved with intercropping when interspecific competition is lower than intra-specific (Zhang et al. 2011). The assessment of competition and agronomic advantages of intercropping can be conducted using indices such as land equivalent ratio (LER), relative crowding coefficient (*K*), competitive ratio (CR), aggressivity (*A*) and actual yield loss (AYL)

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(McGilchrist 1965; Willey & Rao 1980; Connolly et al. 2001; Weigelt & Jolliffe 2003). To our knowledge, such investigation has not been carried for intercropping systems involving bottle gourd and cassava.

The objective of this study, based on the six competition indices, was to determine, the promising cropping systems involving cassava and bottle gourd in terms of agronomic advantages in seed (bottle gourd) and tuber (cassava) yields. Experiments were conducted during the 2013–2014 and 2014–2015 cropping seasons using two species, in 27 crop association schemes taking into account plant cultivar (three varieties of each crop) and the planting density (three densities of cassava).

Materials and methods

Site description

The study was conducted at the experimental farm of Manfla, a village located between 7°00′N–7°26′N and longitudes 6° 00′W–6°30′W and 400 km North Abidjan (Côte d'Ivoire). Manfla has a bimodal rainfall distribution with a long rainy season from March to July and a short rainy season from September to November. The rainy seasons at the target site are separated by a short period dry (July–August) and a long dry season (December–February). Annual rainfall varies from 800 to 1400 mm with a long-term mean of 1200 mm and the annual mean temperature is 27°C. The experiments were established in a sandy loam soil with pH = 6.45, sandy (57%), loam (36%), clay (7%), organic matter content (6%), N–NO_3 (3.5 ppm), available P (24.4 ppm) and 0.45 ppm of K (0–20 cm depth). The vegetation is a woodland savanna (Kouassi & Zoro Bi 2010).

Plant materials

The plant materials used were three popular varieties of cassava and three morphotypes of bottle gourd. The varieties of cassava were locally named *blêbou*, *yacé* and *six mois* and were collected on-farm in the village of Manfla. The initial development of *six mois* is lower than that of *blêbou* and *yacé*. *Yacé* and *six mois* had a spreading habit but branching begins at 6 months after planting. In contrast, *blêbou* had an upright habit but had dense foliage and rapid growth. *Yacé* is the traditional variety of manioc ideal for processing cassava into *attiéké* (semolina of cassava). *Six mois* and *blêbou* were the traditional varieties of manioc ideal for good cooking and good taste (cassava food). Three morphotypes of bottle gourd were used: dark green and round fruit (DGR); light green and round fruit (LGR); and light green and long fruit (LGL). Seeds of bottle gourd were obtained from the collection of the University of Nangui Abrogua (Abidjan, Côte d'Ivoire).

Experimental design and sampling

The experimental design was a randomized complete block design with two replications of 27 intercropping treatments (3 cultivars of cassava × 3 morphotypes of bottle gourd × 3 planting densities). The experimental plot size was 31× 100 m. The subplot (treatment) size was 4 × 5 m. Treatments were separated by a 2 m buffer zone. The effect of different cropping patterns employing simple additive design was evaluated. Thus, bottle gourd plant population density was maintained at 2500 plants/hectare (2 × 2 m), while cassava plant density varied in the intercrops (Table 1) established by either alternate rows of cassava and bottle gourd. The treatments were therefore:

Table 1. Experimental layout for the evaluation of bottle and cassava intercropped at varying densities of cassava.

Treatments	Bottle gourd (plants/plot)	Cassava (plants/plot)
Monocropped bottle gourd	6	0
Monocropped cassava	0	42
Monocropped cassava	0	24
Monocropped cassava	0	18
Intercropping bottle gourd-cassava (6:42)	6	42
Intercropping bottle gourd-cassava (6:24)	6	24
Intercropping bottle gourd-cassava (6:18)	6	18

(i) Bottle/cassava intercrop (cassava planted at 1× 2 m at 1 plant/stand with plant population density of 5000 plants/hectare).
(ii) Bottle/cassava intercrop (cassava planted at 1 × 1 m at 1 plant/stand with plant population density of 10,000 plants/hectare).
(iii) Bottle/cassava intercrop (maize planted at 1 × 0.5 m at 1 plant/stand with plant population density of 20,000 plants/hectare). Sowings of the bottle gourd were performed manually by planting twice more seeds than the expected plant densities and then, rows were thinned to the required densities. Cassava and bottle gourd were planted at the same time. For mono- and intercropping, no fertilizer and insecticide were applied to enhance plant production or to control diseases and pests. Weed control was performed manually with a hoe. Bottle gourd was harvested at maturity (4 months) and cassava tubers were harvested 10 months after planting. Seeds of bottle gourd were extracted from fruit, weighed after adjusting the moisture to 10%, while the fresh weight of cassava tubers was taken.

Yield estimate

The yield parameter (Y_c) of cassava was calculated as the product of the average weight of tuberous root per plant and the number of plants (calculated for one hectare according to densities tested: $D = 5000$, 10,000 and 20,000 plants/ha). The yield parameter (Y_g) of bottle gourd was calculated using the following formula:

$$Y_g = \frac{\text{WSF} \times \text{NFP}}{S} \times 10,000,$$

where Y_g is the yield of gourd, WSF is the weight of seeds per fruit, NFP is the number of fruit per plot and S is the surface of the subplot.

Competitive indices

To evaluate the extent of competition between different intercropped species, different indices were suggested (Connolly et al. 2001; Weigelt & Jolliffe 2003). In this present study, the competitive behavior of component crops in different bottle gourd-cassava planting patterns were determined in terms of LER, area time equivalent ratio (ATER), A, K, CR and AYL

Land equivalent ratio

The advantages of bottle gourd-cassava intercropping were evaluated using the LER (Willey & Osiru 1972). LER indicates the efficiency of intercropping, using the environmental resources compared to monocropping (Mead & Willey 1980). When LER > 1 the intercropping favors the growth and yield of the species. In contrast, when LER < 1 there is no intercropping advantage and the interspecific competition is stronger than the interspecific interaction within intercropping system (Zhang et al. 2011). LER was calculated as

$$\mathrm{LER} = (\mathrm{LER}_{\mathrm{cassava}} + \mathrm{LER}_{\mathrm{gourd}}); \quad \mathrm{LER}_{\mathrm{cassava}} = \frac{Y_{\mathrm{ci}}}{Y_{\mathrm{c}}}; \quad \mathrm{LER}_{\mathrm{gourd}} = \frac{Y_{\mathrm{gi}}}{Y_{\mathrm{g}}},$$

where Y_c is the yield of cassava as sole crops, Y_g is the yield of bottle gourd as sole crops, Y_{ci} is the yield of cassava as intercrops and Y_{gi} is the yield of bottle gourd as intercrops.

Area time equivalent ratio

ATER provides more realistic comparison of the yield advantage of intercropping over monocropping in terms of time taken by component crops in the intercropping systems (Hiebsch & McCollum 1987; Aasim et al. 2008; Yahuza 2011). ATER was calculated using the following formula:

$$\mathrm{ATER} = (\mathrm{ATER}_{\mathrm{cassava}} + \mathrm{ATER}_{\mathrm{gourd}}); \quad \mathrm{ATER}_{\mathrm{cassava}} = \frac{Y_{\mathrm{ci}}}{Y_{\mathrm{c}}} \times \frac{T_{\mathrm{c}}}{T_{\mathrm{i}}}; \quad \mathrm{ATER}_{\mathrm{gourd}} = \frac{Y_{\mathrm{gi}}}{Y_{\mathrm{g}}} \times \frac{T_{\mathrm{g}}}{T_{\mathrm{i}}},$$

where T_c is the duration of growth cycle of cassava; T_g is the duration of growth cycle bottle gourd and T_i is the duration in days of the species with the longest growing period.

Aggressivity

Aggressivity (A) is a competitive index, which is a measure of how much the relative yield of one crop component is greater than that of another (McGilchrist 1965). Aggressivity is expressed as

$$A_{\mathrm{cassava}} = \frac{Y_{\mathrm{ci}}}{Y_{\mathrm{c}} \times P_{\mathrm{ci}}} - \frac{Y_{\mathrm{gi}}}{Y_{\mathrm{g}} \times P_{\mathrm{gi}}}$$

$$A_{\mathrm{gourd}} = \frac{Y_{\mathrm{gi}}}{Y_{\mathrm{g}} \times P_{\mathrm{gi}}} - \frac{Y_{\mathrm{ci}}}{Y_{\mathrm{c}} \times P_{\mathrm{ci}}},$$

where P_{ci} is the sown proportion of cassava in mixture with bottle gourd and P_{gi} is the sown proportion of bottle gourd in mixture.

If $A_{cassava}$ or $A_{gourd} = 0$, both crops are equally competitive. When $A_{cassava}$ is positive then the cassava species is dominant and when it is negative then bottle gourd is the dominating species.

Relative crowding coefficient

De Wit (1960) introduced the relative crowding coefficient (RCC or K) in plant competition theory. The K allowed evaluating and comparing the competitive ability of one species to the other in a mixture (Zhang et al. 2011). The K was calculated as

$$K = K_{\mathrm{cassava}} \times K_{\mathrm{gourd}}; \quad K_{\mathrm{cassava}} = \frac{Y_{\mathrm{ci}} \times P_{\mathrm{gi}}}{(Y_{\mathrm{c}} - Y_{\mathrm{ci}}) \times P_{\mathrm{ci}}}; \quad K_{\mathrm{gourd}} = \frac{Y_{\mathrm{gi}} \times P_{\mathrm{ci}}}{(Y_{\mathrm{g}} - Y_{\mathrm{gi}}) \times P_{\mathrm{ci}}},$$

If $K_{cassava}$ is greater than K_{gourd}, cassava is more competitive than bottle. Also, when the product of the two coefficients ($K_{cassava}$ and K_{gourd}) is greater than 1 there is a yield advantage, when K is equal to 1 there is no yield advantage, and when it is less than 1 there is a disadvantage.

Competitive ratio

The CR, introduced by Willey and Rao (1980), was used as an indicator to evaluate the competitive ability of different species in intercropping (Weigelt & Jolliffe 2003; Uddin et al. 2014). It was calculated by following formula (Willey & Rao 1980; Uddin et al. 2014):

$$\mathrm{CR}_{\mathrm{cassava}} = \frac{\mathrm{LER}_{\mathrm{c}}}{\mathrm{LER}_{\mathrm{g}}} \times \frac{P_{\mathrm{gi}}}{P_{\mathrm{ci}}}; \quad \mathrm{CR}_{\mathrm{gourd}} = \frac{\mathrm{LER}_{\mathrm{g}}}{\mathrm{LER}_{\mathrm{c}}} \times \frac{P_{\mathrm{ci}}}{P_{\mathrm{gi}}},$$

If $CR_{cassava} > 1$, cassava is more competitive than bottle gourd, and if $CR_{cassava} < 1$, then cassava is less competitive than bottle gourd (Zhang et al. 2011).

Actual yield loss

The AYL is the proportionate yield loss or gain of intercrops in comparison to the respective sole crop. In addition, partial $AYL_{cassava}$ and AYL_{gourd} represent the proportionate yield loss or gain of each species in intercropping compared to their yield in sole crops. The positive or negative values of AYL indicate the advantage or disadvantage of the intercropping (Dhima et al. 2007). The AYL is calculated using the following formula (Banik 1996):

$$\mathrm{AYL}_{\mathrm{cassava}} = \left\{ \left(\frac{Y_{\mathrm{ci}}}{P_{\mathrm{ci}}}\right) | \left(\frac{Y_{\mathrm{c}}}{P_{\mathrm{c}}}\right) \right\} - 1;$$

$$\mathrm{AYL}_{\mathrm{gourd}} = \left\{ \left(\frac{Y_{\mathrm{gi}}}{P_{\mathrm{gi}}}\right) | \left(\frac{Y_{\mathrm{g}}}{P_{\mathrm{g}}}\right) \right\} - 1,$$

$$\mathrm{AYL} = \mathrm{AYL}_{\mathrm{cassava}} + \mathrm{AYL}_{\mathrm{gourd}}.$$

Statistical analysis

Experiments were carried out for two years. However, year has no significant effect on competitive indices and yield of crop. Thus, the data of both years were combined for statistical analysis. Mean values and standard deviations were calculated for each of the six competitive indices with respect to variety and densities. Combined multivariate analysis of variance (MANOVA) appropriate to three factors (bottle gourd, cassava and density) and several independent variables was performed to compare gourd, cassava and density effect, as well as the interaction. This allowed the identification of significant factors based on a vector of dependent variables. The general linear models procedure of the SAS statistical package version 9.1 (SAS 2004) was used to identify traits contributing to differences when MANOVA revealed significant difference for a factor. Least significant difference multiple range-tests were used to identify differences among means on gourd, cassava and interactions.

Table 2. MANOVA performed to test the overall effect of cassava and bottle gourd cultivar/morphotype and density on competition indices and yield.

	Competitive indices		Bottle gourd yield		Cassava yield	
Sources of variation	d.f.	*P*	d.f.	*P*	d.f.	*P*
Gourd	18	<.001	2	<.001	2	.146
Cassava	18	<.001	2	<.001	2	<.001
Density	18	<.001	2	<.001	2	<.001
Gourd × cassava	36	<.001	4	<.001	4	.363
Cassava × density	36	<.001	4	<.001	4	<.001
Gourd × density	36	<.001	4	<.001	4	.947
Gourd × cassava × density	72	<.001	8	<.001	8	.367

Table 3. Fresh tuber yield of cassava varieties in the intercrop.

Cassava	Plant ratio (gourd:cassava)	Fresh tubers yield (t.ha^{-1})
Blêbou	6:42	9.84 ± 0.21^{f}
	6:24	15.50 ± 0.22^{b}
	6:18	11.40 ± 0.21^{e}
Six mois	6:42	8.50 ± 0.130^{h}
	6:24	12.51 ± 0.13^{c}
	6:18	8.56 ± 0.17^{h}
Yacé	6:42	9.47 ± 0.14^{g}
	6:24	18.47 ± 0.12^{a}
	6:18	11.77 ± 0.12^{d}
F		9623.07
P		<.001

Mean values followed by the same superscript were not significantly different ($P \geq .05$).

Results

Overall competitive indices and yield variation with respect to crop and sowing density

MANOVA showed that bottle gourd and cassava crop, and sowing density had a significant ($P < .05$) effect on both bottle gourd dried seed yield and competitive indices. Bottle gourd had no significant ($P > .05$) effect on the yield of cassava varieties. Interaction of gourd × cassava × density had significant ($P < .05$) effect on the dried seed yield of bottle gourd and the competitive indices, but had no significant effect on the fresh tuber yield of cassava (Table 2). Thus, to perform the analysis of variance for the yield of cassava, the double interaction (cassava × density) was considered (Table 3), while the triple interaction (gourd × cassava × density) was considered for the yield of the gourd (Table 4) and competitive indices (Tables 5–7).

Effect of intercropping patterns on tuber yield of cassava

The tuber yield of cassava was not significantly affected by the bottle gourd component (Table 2). However, for each variety of cassava, the high density (6:42) produced low yield. The high yield of each variety of cassava was obtained with medium density of cassava (6:24). With respect to variety, the highest yield was obtained with *yacé* planted at medium density (6:24). Thus, at high density, cassava produced lower yield than that of low and medium densities (Table 3).

Effect of intercropping patterns on dried seed yield of bottle gourd

Significant differences were found for the dried seed yield of the bottle gourd in various cropping ratios (Table 4). This variable increased with reduction of ratio of cassava plant in mixture. For each of the three morphotypes of the bottle gourd, the better yield was obtained when it was cultivated under low ratio (6:18) of cassava variety *six mois* (Table 4). Among planting patterns, the highest dried seed yield

Table 4. Dried seeds yield of bottle gourd in the intercrop with cassava.

Gourd	Cassava	Plant ratio (gourd:cassava)	Dried seeds yield (kg ha^{-1})
DGR	*Blêbou*	6:42	34.54 ± 0.74^{w}
		6:24	92.31 ± 0.29^{p}
		6:18	137.42 ± 1.51^{l}
	Six mois	6:42	63.20 ± 0.48^{s}
		6:24	163.22 ± 1.10^{h}
		6:18	218.93 ± 1.73^{d}
	Yacé	6:42	43.33 ± 0.63^{v}
		6:24	98.30 ± 0.41^{o}
		6:18	141.20 ± 1.14^{k}
LGL	*Blêbou*	6:42	39.19 ± 6.49^{w}
		6:24	98.63 ± 7.17^{o}
		6:18	149.37 ± 13.44^{j}
	Six mois	6:42	73.28 ± 9.03^{r}
		6:24	184.80 ± 28.58^{g}
		6:18	269.89 ± 37.30^{b}
	Yacé	6:42	50.32 ± 11.50^{u}
		6:24	110.71 ± 2.03^{n}
		6:18	158.65 ± 13.51^{i}
LGR	*Blêbou*	6:42	52.67 ± 0.75^{u}
		6:24	113.71 ± 0.57^{m}
		6:18	178.52 ± 1.84^{f}
	Six mois	6:42	91.38 ± 0.36^{p}
		6:24	246.58 ± 1.81^{c}
		6:18	342.57 ± 4.89^{a}
	Yacé	6:42	75.26 ± 0.30^{q}
		6:24	155.32 ± 3.19^{i}
		6:18	185.57 ± 1.23^{e}
F			4.8
P			<.001

Mean values followed by the same superscript were not significantly different ($P \geq .05$).
DGR, dark green and round fruit; LGR, light green and round fruit; LGL, light green and long fruit.

Table 5. LER and ATER for the intercrop of bottle gourd and cassava sown at three planting ratios.

Treatments				
Gourd	Cassava	Plant ratio (gourd:cassava)	LER	ATER
DGR	*Blêbou*	6:42	0.793 ± 0.02^{o}	0.767 ± 0.02
		6:24	1.008 ± 0.02^{fg}	0.938 ± 0.02
		6:18	0.945 ± 0.03^{i}	0.841 ± 0.03
	Six mois	6:42	0.889 ± 0.01^{k}	0.841 ± 0.01
		6:24	1.143 ± 0.02^{b}	1.019 ± 0.02
		6:18	1.020 ± 0.02^{ef}	0.854 ± 0.02
	Yacé	6:42	0.815 ± 0.01^{mn}	0.782 ± 0.01
		6:24	1.058 ± 0.01^{d}	0.983 ± 0.01
		6:18	0.921 ± 0.01^{j}	0.814 ± 0.01
LGL	*Blêbou*	6:42	0.805 ± 0.02^{no}	0.778 ± 0.02
		6:24	1.012 ± 0.01^{ef}	0.942 ± 0.01
		6:18	0.946 ± 0.03^{i}	0.840 ± 0.03
	Six mois	6:42	0.890 ± 0.01^{k}	0.838 ± 0.01
		6:24	1.149 ± 0.02^{b}	1.021 ± 0.02
		6:18	1.069 ± 0.02^{d}	0.876 ± 0.02
	Yacé	6:42	0.814 ± 0.02^{mn}	0.780 ± 0.02
		6:24	1.057 ± 0.01^{d}	0.982 ± 0.01
		6:18	0.933 ± 0.01^{ij}	0.819 ± 0.01
LGR	*Blêbou*	6:42	0.829 ± 0.03^{m}	0.792 ± 0.02
		6:24	1.027 ± 0.02^{e}	0.946 ± 0.02
		6:18	0.992 ± 0.04^{g}	0.865 ± 0.04
	Six mois	6:42	0.918 ± 0.02^{j}	0.853 ± 0.02
		6:24	1.228 ± 0.02^{a}	1.053 ± 0.02
		6:18	1.144 ± 0.02^{b}	0.900 ± 0.01
	Yacé	6:42	0.847 ± 0.02^{l}	0.793 ± 0.02
		6:24	1.120 ± 0.01^{c}	1.009 ± 0.01
		6:18	0.969 ± 0.01^{h}	0.838 ± 0.01
F			6.0	1.4
P			<.001	.187

Mean values followed by the same superscript were not significantly different ($P \geq .05$).
DGR, dark green and round fruit; LGR, light green and round fruit; LGL, light green and long fruit

Table 6. Aggressivity (*A*) and CR for intercrop of cassava with bottle gourd for three planting ratios.

Treatments			CR		*A*	
Gourd	Cassava	Plant ratio (gourd:cassava)	$CR_{cassava}$	CR_{gourd}	$A_{cassava}$	A_{gourd}
DGR	*Blêbou*	6:42	2.45 ± 0.10^{a}	0.41 ± 0.02^{r}	0.51 ± 0.03^{c}	-0.51 ± 0.03^{q}
		6:24	1.91 ± 0.04^{cd}	0.52 ± 0.01^{op}	0.53 ± 0.02^{ab}	-0.53 ± 0.02^{rs}
		6:18	1.48 ± 0.06^{h}	0.68 ± 0.03^{l}	0.33 ± 0.04^{g}	-0.33 ± 0.04^{m}
	Six mois	6:42	1.45 ± 0.03^{h}	0.69 ± 0.02^{l}	0.29 ± 0.02^{h}	-0.29 ± 0.02^{l}
		6:24	1.13 ± 0.02^{mn}	0.88 ± 0.01^{g}	0.14 ± 0.02^{mn}	-0.14 ± 0.02^{fg}
		6:18	0.89 ± 0.02^{p}	1.12 ± 0.03^{d}	-0.12 ± 0.03^{q}	0.12 ± 0.03^{c}
	Yacé	6:42	1.98 ± 0.07^{b}	0.51 ± 0.02^{q}	0.43 ± 0.02^{de}	-0.43 ± 0.02^{op}
		6:24	1.87 ± 0.04^{cd}	0.53 ± 0.01^{o}	0.54 ± 0.02^{a}	-0.54 ± 0.02^{s}
		6:18	1.38 ± 0.02^{i}	0.72 ± 0.01^{k}	0.27 ± 0.02^{hi}	-0.27 ± 0.02^{kl}
LGL	*Blêbou*	6:42	2.42 ± 0.07^{a}	0.41 ± 0.01^{r}	0.51 ± 0.02^{bc}	-0.51 ± 0.02^{qr}
		6:24	1.91 ± 0.03^{d}	0.52 ± 0.01^{op}	0.53 ± 0.02^{a}	-0.53 ± 0.02^{s}
		6:18	1.45 ± 0.05^{h}	0.69 ± 0.02^{l}	0.32 ± 0.04^{g}	-0.32 ± 0.04^{m}
	Six mois	6:42	1.32 ± 0.02^{j}	0.76 ± 0.01^{j}	0.22 ± 0.02^{k}	-0.22 ± 0.02^{i}
		6:24	1.10 ± 0.03^{no}	0.91 ± 0.02^{f}	0.11 ± 0.03^{o}	-0.11 ± 0.03^{e}
		6:18	0.77 ± 0.02^{q}	1.29 ± 0.03^{b}	-0.29 ± 0.02^{r}	0.29 ± 0.02^{b}
	Yacé	6:42	1.94 ± 0.05^{c}	0.52 ± 0.01^{pq}	0.42 ± 0.02^{e}	-0.42 ± 0.02^{o}
		6:24	1.86 ± 0.02^{e}	0.54 ± 0.01^{o}	0.54 ± 0.01^{a}	-0.54 ± 0.01^{s}
		6:18	1.31 ± 0.02^{jk}	0.76 ± 0.01^{j}	0.23 ± 0.02^{jk}	-0.23 ± 0.02^{ij}
LGR	*Blêbou*	6:42	1.75 ± 0.05^{f}	0.57 ± 0.02^{n}	0.38 ± 0.03^{f}	-0.38 ± 0.03^{n}
		6:24	1.66 ± 0.03^{g}	0.60 ± 0.01^{m}	0.44 ± 0.02^{d}	-0.44 ± 0.02^{p}
		6:18	1.23 ± 0.06^{l}	0.81 ± 0.04^{h}	0.20 ± 0.05^{l}	-0.20 ± 0.05^{h}
	Six mois	6:42	1.07 ± 0.02^{o}	0.94 ± 0.02^{e}	0.06 ± 0.02^{p}	-0.06 ± 0.02^{d}
		6:24	0.80 ± 0.02^{q}	1.25 ± 0.03^{c}	-0.29 ± 0.03^{r}	0.29 ± 0.03^{b}
		6:18	0.61 ± 0.01^{r}	1.65 ± 0.02^{a}	-0.64 ± 0.02^{s}	0.64 ± 0.02^{a}
	Yacé	6:42	1.21 ± 0.04^{l}	0.82 ± 0.02^{h}	0.15 ± 0.02^{m}	-0.15 ± 0.02^{g}
		6:24	1.27 ± 0.03^{k}	0.79 ± 0.02^{i}	0.25 ± 0.02^{ij}	-0.25 ± 0.02^{jk}
		6:18	1.14 ± 0.01^{m}	0.88 ± 0.01^{g}	0.12 ± 0.01^{no}	-0.12 ± 0.01^{ef}
F			49.9	106.1	68.50	68.50
P			<.001	<.001	<.001	<.001

Mean values followed by the same superscript were not significantly different ($P \geq .05$).
DGR, dark green and round fruit; LGR, light green and round fruit; LGL, light green and long fruit.

Table 7. Relative crowding coefficient (*K*) and AYL for intercrop of cassava with bottle gourd in three planting ratios.

Treatments			Relative crowding coefficient (*K*)			AYL		
Gourd	Cassava	Plant ratios (gourd:cassava)	K_{gourd}	$K_{cassava}$	K	AYL_{gourd}	$AYL_{cassava}$	AYL
DGR	*Blêbou*	6:42	0.320 ± 0.01^{u}	0.432 ± 0.05	0.138 ± 0.01	-0.650 ± 0.01^{v}	-0.142 ± 0.02	-0.792 ± 0.02^{p}
		6:24	0.528 ± 0.01^{r}	2.113 ± 0.44	1.117 ± 0.23	-0.416 ± 0.01^{r}	0.114 ± 0.02	-0.301 ± 0.02^{k}
		6:18	0.631 ± 0.01^{no}	1.155 ± 0.22	0.729 ± 0.14	-0.304 ± 0.01^{n}	0.029 ± 0.04	-0.275 ± 0.04^{ij}
	Six mois	6:42	0.608 ± 0.01^{p}	0.609 ± 0.06	0.370 ± 0.03	-0.360 ± 0.01^{p}	-0.075 ± 0.02	-0.435 ± 0.02^{m}
		6:24	1.042 ± 0.01^{f}	3.915 ± 1.15	4.083 ± 1.21	0.033 ± 0.01^{f}	0.170 ± 0.02	0.204 ± 0.02^{d}
		6:18	1.151 ± 0.02^{d}	0.970 ± 0.09	1.117 ± 0.11	0.109 ± 0.01^{d}	-0.009 ± 0.02	0.100 ± 0.03^{e}
	Yacé	6:42	0.406 ± 0.01^{t}	0.455 ± 0.04	0.185 ± 0.01	-0.560 ± 0.01^{t}	-0.130 ± 0.02	-0.691 ± 0.01^{o}
		6:24	0.569 ± 0.01^{q}	3.697 ± 0.86	2.101 ± 0.47	-0.376 ± 0.01^{q}	0.167 ± 0.02	-0.209 ± 0.01^{g}
		6:18	0.655 ± 0.01^{lm}	0.963 ± 0.06	0.632 ± 0.04	-0.282 ± 0.01^{l}	-0.009 ± 0.01	-0.292 ± 0.02^{jk}
LGL	*Blêbou*	6:42	0.328 ± 0.00^{u}	0.458 ± 0.06	0.150 ± 0.02	-0.641 ± 0.00^{u}	-0.130 ± 0.02	-0.771 ± 0.03^{p}
		6:24	0.532 ± 0.00^{r}	2.177 ± 0.30	1.158 ± 0.16	-0.412 ± 0.00^{r}	0.119 ± 0.02	-0.293 ± 0.02^{jk}
		6:18	0.645 ± 0.02^{mn}	1.136 ± 0.21	0.734 ± 0.15	-0.292 ± 0.01^{m}	0.026 ± 0.04	-0.265 ± 0.05^{hi}
	Six mois	6:42	0.665 ± 0.01^{l}	0.585 ± 0.04	0.389 ± 0.03	-0.305 ± 0.01^{n}	-0.081 ± 0.01	-0.387 ± 0.02^{l}
		6:24	1.080 ± 0.02^{e}	4.508 ± 2.97	4.866 ± 3.18	0.063 ± 0.01^{e}	0.171 ± 0.03	0.234 ± 0.03^{c}
		6:18	1.424 ± 0.01^{c}	0.996 ± 0.10	1.419 ± 0.15	0.287 ± 0.01^{c}	-0.002 ± 0.02	0.285 ± 0.03^{b}
	Yacé	6:42	0.413 ± 0.00^{t}	0.451 ± 0.05	0.186 ± 0.02	-0.553 ± 0.00^{t}	-0.133 ± 0.02	-0.687 ± 0.02^{o}
		6:24	0.571 ± 0.01^{q}	3.582 ± 0.83	2.049 ± 0.48	-0.374 ± 0.01^{q}	0.165 ± 0.02	-0.209 ± 0.02^{g}
		6:18	0.701 ± 0.01^{j}	0.967 ± 0.04	0.678 ± 0.03	-0.241 ± 0.01^{k}	-0.008 ± 0.01	-0.250 ± 0.01^{h}
LGR	*Blêbou*	6:42	0.466 ± 0.00^{s}	0.478 ± 0.08	0.223 ± 0.04	-0.499 ± 0.00^{s}	-0.123 ± 0.03	-0.623 ± 0.02^{n}
		6:24	0.623 ± 0.01^{o}	2.151 ± 0.45	1.341 ± 0.29	-0.326 ± 0.00^{o}	0.116 ± 0.02	-0.210 ± 0.03^{g}
		6:18	0.803 ± 0.01^{i}	1.249 ± 0.36	1.005 ± 0.29	-0.155 ± 0.01^{j}	0.041 ± 0.06	-0.113 ± 0.06^{f}
	Six mois	6:42	0.850 ± 0.00^{h}	0.614 ± 0.07	0.522 ± 0.06	-0.133 ± 0.00^{i}	-0.074 ± 0.02	-0.207 ± 0.02^{g}
		6:24	1.649 ± 0.02^{a}	4.169 ± 1.69	6.860 ± 2.71	0.460 ± 0.01^{b}	0.170 ± 0.03	0.630 ± 0.02^{a}
		6:18	2.048 ± 0.05^{a}	0.944 ± 0.06	1.937 ± 0.17	0.622 ± 0.02^{a}	-0.015 ± 0.02	0.607 ± 0.03^{a}
	Yacé	6:42	0.684 ± 0.00^{k}	0.450 ± 0.05	0.308 ± 0.03	-0.287 ± 0.00^{lm}	-0.133 ± 0.02	-0.420 ± 0.02^{m}
		6:24	0.900 ± 0.02^{g}	3.898 ± 1.19	3.509 ± 1.07	-0.081 ± 0.02^{g}	0.170 ± 0.02	0.089 ± 0.02^{e}
		6:18	0.845 ± 0.01^{h}	1.000 ± 0.03	0.846 ± 0.03	-0.120 ± 0.00^{h}	0.000 ± 0.01	-0.120 ± 0.01^{f}
F			498.3	0.204	1.376	373.2	0.647	54.44
P			<.001	.990	.211	<.001	.737	<.001

Mean values followed by the same superscript were not significantly different ($P \geq 0.05$).
DGR: dark green and round fruit, LGR: light green and round fruit, LGL: light green and long fruit.

(342.57 ± 4.89 kg ha^{-1}) of bottle gourd was obtained from LGR-*six mois* at 6:18 ratio (Table 4).

Land equivalent ratio and area time equivalency ratio

The statistical analysis of data (Table 5) indicated that intercropping combinations had a significant ($P < .05$) effect only on the LER. LER was greater than 1.00 in intercropped bottle gourd-cassava at 6:24 ratios and also when the bottle gourd morphotypes were associated with the cultivar *six* mois at 6:18 ratio. The highest value of LER (1.23) was recorded in LGR-*six mois* (6:24), while the lower LER (0.79) was found in DGR-*blêbou* (6:42). In all the treatments, LER values were greater than the ATER. On the other hand, ATER values were lower than 1.00 in all the cases, except when the morphotypes of bottle gourd were intercropped with the cassava cultivar *six mois* at 6:24 planting ratios.

Aggressivity and competitive ratio

The competitive ability of the three cultivars of cassava and the three morphotypes of bottle gourd according to the three densities was also estimated through aggressivity and rate of competitiveness. The results showed that the variation ($P < .05$) of aggressivity (A) and CR depended on the configuration of the intercropping systems (Table 6).

The aggressivity values indicated that cassava cultivars *blêbou* and *yacé* ($A_{casava} > 0$) dominated the bottle gourd morphotypes ($A_{gourd} < 0$) in all cropping systems tested. This dominance was more pronounced in the *yacé* association with the bottle gourd morphotype DGR at the ratio 6:18. On the contrary, the bottle gourd was more aggressive in the association where LGR was planted at low ratio (6:18) with the cassava cultivar *six mois*.

In all treatments, the CR of *yacé* and *blêbou* were greater than unity (Table 6). This highest value of CR indicated its superior ability of competition than that of bottle gourd. However, the CR of *six mois* was less than unity when it was intercropped with the bottle gourd component at low density (6:18). In addition, the association LGR-*six mois* at ratio 6:24 indicated that the CR of *six mois* was also less than unity. Finally, *six mois* appeared as a poor competitor in association with the three bottle gourd morphotypes tested.

The aggressivity index (A) and the CR clearly showed that the cassava cultivars *yacé* and *blêbou* were dominant in its intercrop with bottle gourd. In contrast, the cassava cultivar *six mois* was dominated in the intercrop with bottle gourd at ratio 6:18.

Relative crowding coefficient and actual yield loss

The trend observed for the relative crowding coefficient (K) was similar to that obtained with the A and CR. In fact, the values of $K_{cassava}$ were greater than K_{gourd} in all the treatments except in the association of bottle gourd with *six mois* at ratio 6:18. This result indicated the dominance of cassava component except when the cultivar *six mois* was associated with bottle gourd at 6:18 ratio (Table 7). The relative crowding coefficient (K) confirmed that *blêbou* and *yacé* were the most powerful competitor compared to bottle gourd morphotypes tested. In terms of advantage of intercropping systems, K indicated a similar trend with *LER*. There was intercropping advantage in bottle gourd-*blêbou* (6:24), bottle gourd-*yacé* (6:24), bottle gourd-*six mois* (6:24) and bottle gourd-*six mois* (6:18).

In all the treatments, the AYL of the bottle gourd had negative values ($AYL_{gourd} < 0$) in the associations with *blêbou* and *yacé* (Table 7). This result indicated a yield disadvantage for bottle gourd morphotypes. Cassava was dominant because the partial AYL of cassava was greater than this of bottle gourd. However, AYL_{gourd} had positive values in the association bottle gourd-*six mois* at ratios 6:24 and 6:18. This result indicated a yield advantage for bottle gourd. The best value of AYL_{gourd} for each bottle gourd morphotype was found in its association with *six mois* at 6:18, indicating the best combination and planting configuration for this crop.

Positives values of AYL were observed in the association bottle gourd-*six mois* at ratios 6:24 and 6:18 and in the particular case of LGR-*yacé* at 6:24 (Table 7). This result suggested an advantage of intercropping system compared to pure culture. In these cases, there was increase in yield of intercropping system that ranged from 8% to 63% (AYL = +0.08 to +0.63) as compared to sole crop yield. In contrast, in all other mixtures, the AYL ranged from −0.113 to −0.792, indicating a yield loss of 11.3–79.2%, compared with sole crop yield (Table 7). The highest values (0.63 and 0.60) of AYL were found in the association LGR-*six mois* at ratios 6:24 and 6:18, respectively.

Discussion

The objective of this work was to improve the performance of cassava and bottle gourd cultivated in the mixed-cropping system. An evaluation of this was done, first, using six competitive indices (LER, ATER, CR, A, K and AYL) and secondly, through the analysis of returns.

LER reflects the extra advantage of intercropping system over sole cropping system. The highest value of LER (1.23) was recorded in LGR-*six mois* (6:24), indicating that 23% more area was required in a pure cropping system to equal the yield of intercropping (Midya et al. 2005; Dhima et al. 2007). With this cropping pattern, LER was significantly greater than 1.00 indicating an advantage of intercropping over pure stands, in terms of the use of environmental resources for plant growth (Mead & Willey 1980). On the other hand, the high value of LER observed, revealed that interspecific interaction or complementarity was greater than the competition so that intercropping resulted in greater land-use efficiency. Indeed, high performance in terms of LER is obtained in plant communities with low competition (Nassab et al. 2011; Zhang et al. 2011).

Values of LER greater than 1.00 have been reported for sorghum-bottle gourd intercropping (Chimonyo et al. 2016), cassava-legumes intercropping (Islami et al. 2011; Mbah & Ogidi 2012; Hidoto & Loha 2013), and for cassava-maize-egusi melon intercropping (Ijoyah et al. 2012). In this study, LER values were greater than those of the ATER, indicating the overestimation of resource utilization by LER. Indeed, Hiebsch and McCollum (1987) stated that it is likely that LER overestimates the advantage of intercropping when component crops differ in growth duration. When land coverage time by intercrop components is different, ATER provides better estimates than LER (Awal et al. 2007). In this study, the values of LER showed an advantage ranged from 1% to 23%, while the values of ATER indicated an advantage ranged from 1% to 5%. Similar results demonstrating better environmental resources utilization in intercropping have also been reported by Aasim et al. (2008) and Uddin et al. (2014) for cotton intercropped with cowpea and wheat intercropped with peanut, respectively. However, neither ATER nor LER can account for crops' competitive abilities in intercropping.

The competitive abilities of component crops in intercropping can be evaluated by A, K and CR (Weigelt & Jolliffe 2003; Wahla et al. 2009). Li et al. (2001) reported that the yield of an intercropping system is positively associated with the interspecific competition of the component crops. According to the authors, the interspecific competition including above-ground and below-ground competition is defined as the interaction between two species that reduces the fitness of one or both of them. In this study, the component crops did not exhibit equal competitive intensity. According to the values obtained for *A*, *K* and CR, bottle gourd, the LGR morphotype was the dominant species, only when it was associated with the cassava cultivar *six mois* at density 6:18. However, in the other configurations, cassava components were dominant. This clearly showed that *blêbou* and *yacé* were the best competitor compared to bottle gourd morphotypes, while *six mois* was less competitive than bottle gourd, particularly in the association gourd-*six mois* at ratio 6:18. The greater competitiveness of cassava in the intercropping system with bottle gourd might be attributed to shading by the cassava crop. Indeed, the tall-growing cassava intercropped with bottle gourd or the high cassava proportion in the mixtures could affect light interception by bottle gourd. Oroka (2012) found that cassava was the dominant species in cassava-groundnut intercropping systems. In terms of the advantage of intercropping systems, *K* indicated similar trends with LER. Thus, there were intercropping advantages in bottle gourd-*cassava* at 6:24 ratios and bottle gourd-*six mois* at 6:18.

The AYL index gave the proportionate yield loss or gain of intercrops in comparison to the respective sole crop. According to Banik et al. (2000), AYL gives more precise information about the competition between and within the component crops than the other indices.

A similar trend to that of *A*, CR and *K* was also observed for AYL. AYL_{gourd} had negative values in the bottle gourd-*blêbou* and bottle gourd-*yacé* mixtures, which indicated a yield disadvantage for bottle gourd, probably due to the exhaustive effect of *blêbou* and *yacé* and shading in the early growth stage of bottle gourd crop. It was also revealed that *blêbou* and *yacé* were dominant crops than bottle gourd in association. In contrast, AYL_{gourd} had positive values in association bottle gourd-*six mois* at ratios 6:24 and 6:18. This result indicated a yield advantage for bottle gourd crops, probably because *six mois* had low shading on bottle gourd component when grown in association at these densities. Moreover, the values of AYL for bottle gourd were greater than for *six mois* in both seedling ratios (6:24 and 6:18). The corresponding value of AYL for *six mois* was also low. This indicated that bottle gourd morphotypes were more competitive than *six mois*. The best value of AYL_{gourd} for each bottle gourd morphotype was found in their association with cassava cultivar *six mois* (6:18), indicating the best combination and planting configuration for bottle gourd in such an association pattern. The highest value (0.65) of AYL_{gourd} was found in LGR-*six mois* intercrop (6:18).

The quantification of yield loss or gain due to intercropping or sowing density can be obtained with partial AYL which shows yield loss or gain by negatives or positives values (Dhima et al. 2007). Results revealed that gourd-cassava intercrop had positive values of AYL in the association of bottle gourd-*six mois* at planting ratios 6:24 and 6:18 and in particular, the association of LGR-*yacé* (6:24). These results indicated an advantage of intercropping over the pure stands. The advantages (ranging from 8% to 63%, as measured by AYL) of the intercropping systems found in this study could be attributed to the better utilization of growth resources and to the low competition between the bottle gourd and cassava (Dhima et al. 2007; Nassab et al. 2011; Zhang et al. 2011). Similar results have been reported by other researchers (Dhima et al. 2007; Aasim et al. 2008; Nassab et al. 2011; Das et al. 2012; Muyayabantu et al. 2013; Njad et al. 2013). In all other association patterns, the values of AYL were negatives (from −0.113 to −0.792), corresponding to yield loss of 11.3% to 79.2%, compared to that of sole crop. The differences found between intercropping patterns in this study, could be attributed to the competitive ability of the components and also to other factors such as density, morphology and the different requirements for nutrients.

Conclusions

According to the results of this study, it is advantageous to intercrop bottle gourd (*L. siceraria*) with cassava (*M. esculenta*). This advantage is particularly significant when any one of the three bottle gourd morphotypes is intercropped with the cassava cultivar *six mois* at density 6:24. Cassava cultivars were the dominant component in most treatments. Based on the competitive indices, among the 27 intercropping patterns evaluated, the best combination system was LGR-*six mois* at density 6:24.

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