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Effect of cassava (*Manihot esculenta Crantz*) density under rice-cassava intercropping in the west of Côte d'Ivoire

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ABSTRACT

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In western Côte d'Ivoire, the rice-based cropping system is characterized by cassava intercropping where the rice yield decreases with high densities of cassava. Hence, the need to determine the optimum densities of the associated crops. A trial was set up on plateau soil (Ferralsol) at the main research station of National Center of Agronomic Research in Man city (western Côte d'Ivoire). Five cropping systems were compared in a Fisher experimental design: single rice cropping, single cassava cropping, and three densities of cassava associated with rice (20cm×20cm). The main observations were focused on respective agronomic data of rice and cassava, including yields, land equivalent ratios and area-time equivalent ratios.

The results showed rice grain yield decreasing from 1.78–0.81t ha^{-1} with the increasing density of cassava yielding between 22.39–34.68t ha^{-1}. The optimum density of cassava was 3333 plants ha^{-1} (3m×1m) for yield and LER (>1) coefficient while the ATER ratio was always low (<1) and the difference between cropping cycles was observed. Exploring new calculation methods of the ATER for cassava-rice association was recommended as a future research topic.

Keywords: crops association, rainfed rice, cassava, Ferralsol

INTRODUCTION

Rice is the most popular cereal consumed and cultivated in Côte d'Ivoire. However, the local production of milled rice estimated at 918,000 tons per year provides only 51% of the national requirement (FAO 2016). Based on analysis, more

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than 57% of rice production in Côte d'Ivoire is supplied by rainfed rice cropping (ONDR 2017) in association with cassava (N'Da 2002, Bahan 2012). However, there is no specific technology package to support such a production system to improve the performance of this cropping practice.

The yields observed for rice (0.20mx0.20m) and cassava (1mx1m) are 1t ha^{-1} and 6 to 8t ha^{-1} against, potential yields of 4t ha^{-1}(Bahan et al 2012) and 30t ha^{-1} respectively (N'Zué et al 2005). The observed yield gaps are the motivation for further investigations in order to improve the rice-based cassava system. The performances of associated crop densities need to be evaluated in terms of yield and land use efficiency.

An agronomic trial was initiated in the research station of the National Center of Agronomic Research-NCAR (Man) located at west Côte d'Ivoire to explore the optimum density of cassava in association with rice.

The aim was to 1) characterize the vegetative development (height and numbers of tillers) of each crop for a given cassava density, 2) identify the optimal density of cassava for highest yield of rice and, 3) determine the suitable rice/cassava intercropping for a more efficient land use ratio.

MATERIALS AND METHODS

Experimental Site

The study was carried out at the NCAR station in Man, western Côte d'Ivoire (N 07^{0}20'58", W 07^{0}36'05 " and 337m in elevation). Monomodal (single rainfall season) rainfall pattern is observed from March to October, followed by a dry season (November to February). The preceding vegetation on the experimental site was *Panicum maximum*. The site had been fallow for five years. Enriched coarse particles (>50%) were encountered between 20 and 60cm depth in soil with a clay-sand texture under sandy-clay loam topsoil (0-20cm). Fallow land of 3000m^2 area was cleared manually.

Rice and Cassava Varieties

The genetic material consisted of improved short-cycle rice variety named IDSA 10 (105 days seed-to-maturity cycle), with potential yield of 4t ha^{-1} and a height of 110-115cm at maturity. The associated cassava was also an improved variety named BOCOU 5, characterized by a cycle of 12 months duration with a potential yield estimated at 50t ha^{-1}(in collection).

Experimental Layout

The experiment was conducted in a Randomized Complete Blocks Design (RCBD), of five (5) treatments and 4 replications (blocks). The studied factor was the density of cassava associated with rice. Each treatment was set in a micro-plot of 6mx10m with 1m as inter-plot space in a block (replication). Four replications spaced by 2m were considered for a total of 20 micro-plots. The treatments D0 and D1 were Rice and Cassava mono-crops respectively while D2, D3 and D4 were various intercrop planting densities (Table 1).

Table 1. Description of rice and cassava planting rates for each treatment

Treatment	Rice Sowing Rate	Cassava Planting Rate	System
D0	0.20m×0.20m	0	Rice single cropping
D1	0	1m×1m	Cassava single cropping
D2	0.20m×0.20m	2m×1m	Intercropping
D3	0.20m×0.20m	3m×1m	Intercropping
D4	0.20m×0.20m	4m×1m	Intercropping

After land preparation (clearing and collection of debris), shallow soil tillage (0-20cm) was done. Rice sowing was synchronized with cassava planting during the first year (trial) at the beginning of the cropping season. Two successive rice croppings were carried out during a single cassava cropping cycle. Basal fertilizer composed of NPK (10%, 22%, 22%) was applied at 300kg ha^{-1}. Direct seeding of rice (5-seeds) per hill was applied (20cmx20cm) applying urea (46% N) at 50kg ha^{-1} twice at tillering (21 days after seedling) and flowering (70 days after seedling) stages.

Soil Characterization

Before setting the experiment, five composite soil samples were taken at 0–20cm depth cross diagonal pattern. After air drying, subsamples were taken for physical and chemical analysis.

After harvest, soil was also sampled at 0–20cm depth of each micro-plot (treatment) in across diagonal manner for the following analysis: soil pH was measured by electronic pH-meter in a soil/water ratio of 1/2.5; the soil organic carbon content (Corg) was obtained by Walkley and Black (1934) method; the total nitrogen (N total) content by Kjeldhal (Bremner 1996). Soil content of exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}) as well as that of available iron (Fe^{2+}) were respectively obtained after extraction with ammonium acetate (pH=7) before measurement with atomic absorption spectrometer as described by American Society of Soil Sciences (SSSA) according to Pages et al (1996). Available phosphorus (Pavai) content was also determined by the modified method of Olsen Dabin (Bonneau and Souchier 1994).

DATA COLLECTION

Rice Parameters

Observations were made in a square meter ($1m^2$) and the duration for physiological maturity was counted as the number of days up to 50 % flowering. Plant height, tiller and panicle numbers were also determined. Leaf Area Index (LAI) was measured using a Licor-2000 instrument.

After the harvest ($60m^2$), the number of filled and empty grains as well as the yields were determined. The grain yield (GY) and straw yield (SY) were adjusted for 14% moisture content after sun drying. The total biomass (TDB) was then calculated adding both yields:

$$Gy\ (t\ ha^{-1}) = (\text{dry grain weight } (g) / 60m^2) \times (10000/1000000) \times ((100 - H)/86 \quad (1)$$

H = Moisture rate

$$Sy\ (t\ ha^{-1}) = (\text{dry straw weight } (g) / 60m^2) \times (10000/1000000) \quad (2)$$

$$TDB\ (t\ ha^{-1}) = Gy + Sy \quad (3)$$

Cassava Parameters

Data collections were done excluding the two rows on the border. Plant height was measured at harvest period from ground surface to the apex. Stem diameter (cm) was measured as well as the length and circumference of the tuberous roots. Finally, the fresh weight of the tuberous roots was obtained per micro-plot. Yields and cropping cycle duration were used for assessing the cropping system performance land equivalent ratios (LER) and area-time equivalent ratios (ATER) as below:

$$LER = \frac{\text{Yield of Rice in the intercrop}}{\text{Yield of Rice in the monocrop}} + \frac{\text{Yield of Cassava in the intercrop}}{\text{Yield of Cassava in the monocrop}} \quad (4)$$

$$ATER = [(Ryr \times tr) + (Ryc \times tc)]/T \quad (5)$$

Where:

Ryr and Ryc = Relative yield of rice and cassava respectively;
tr and tc = maturity period of rice and cassava, respectively.
T is the duration of the intercropping.

Statistical Analysis

Analyses of variance and Pearson correlation were performed, using SAS version 9 software at 5% threshold level, to compare the effect of the different associated cassava densities with rice and to explore the relation between studied variables. Principal Component Analysis (PCA) using STATISTICA version 7.1 software was performed for determination of the contribution of variables to cassava yield.

RESULTS AND DISCUSSION

Initial and Final Results of Soil Analyses

The results of physicochemical analyses of the soil are shown in Table 2. An increase in soil acidity is observed along with global reduction of contents regarding soil components (organic carbon, calcium, magnesium and potassium) after cropping while, an enrichment in nitrogen (1.8g kg^{-1}) and available phosphorus (37ppm) contents were observed.

Overall, a slight increase (0.3) of soil acidity occurred during the experiment while nitrogen content was improved (0.4g kg^{-1}) likewise for soil available phosphorus (14 ppm). This contrasts with the content of organic matter and that of exchangeable cations that decreased during the experiment.

Table 2.Soil chemical characteristics in 0–20cm depth before and after the experiment

Parameters	Before	After
pH-$_{H2O}$	4.9	4.6
C (g kg^{-1})	19.1	17.6
N (g kg^{-1})	1.4	1.8
C/N	13.64	9.8
Pav	23	37
Ca^{2+} (cmol kg^{-1})	0.282	0.202
Mg^{2+} (cmol kg^{-1})	0.146	0.047
K^{+} (cmol kg^{-1})	0.128	0.055
ECC (cmol kg^{-1})	11.25	8.33
Fe^{2+} (mg kg^{-1})	50.3	--
Ca/Mg	2/1	4/1
K/Mg	1/1	1/1
(Ca + Mg)/K	3/1	9/2
K/ECC (%)	1.14	0.7

C:organic carbon, N:total nitrogen, Pav:available Phosphorus, Ca:Calcium, Mg:Magnésium, K:Potassium, ECC:exchange cation capacity, -- : not détermined.

Compared to the initial state, the soil exchangeable cations capacity (ECC) declined from 11.23cmol kg^{-1} to 8.33cmol kg^{-1} in a similar trend to the C/N ratio. However, this may be caused by the residual effect of the applied fertilizer and biochemical phenomena prevailing in the rhizosphere (Makinde and Ayoola 2008). Another explanation would be rapid mineralization resulting in increased soil nitrogen content at the end of a cropping cycle as observed, while geochemical changes would occur at the level of clay minerals as kaolinite transformation into illite or smectite (Vendrame et al 2013). In fact, on the summit of the landscape, Ferralsols are characterized by kaolinitic clay depending on the nature of the bedrock and the intensity of the hydrolysis process (Vendrame et al 2013). It is probable that the vegetation cover resulting from the association of the two crops has reduced the hydrolysis effect causing an evolution of kaolinite toward gibbsite by insertion of Al and Mg in the mineralogic network (isomorphic substitution). Hence, the increase of the clay mineral specific surface may have induced greater exchange cations capacity as described by Brindley (1966) and Bailey et al (1971).

The increase in soil acidity, N and Pa contents in the light of our results support this explanation. From these analyses, it is possible to understand the degrading effect of deforestation on the quality of soil due to the fact that the clearing over a short time period induced a demotion of the clay mineral into a less reactive type, contrasting with the effect of the plant cover in the current study. In the current specific study, cassava intercropping with rice appears to be a means of ensuring the sustainability of rice agro-systems, and D3 (3mx1m) of cassava with an average rice yield of about 1t ha^{-1} over two years, can be recommended.

IMPACT OF CASSAVA DENSITY ON RICE DEVELOPMENT

Rice Height

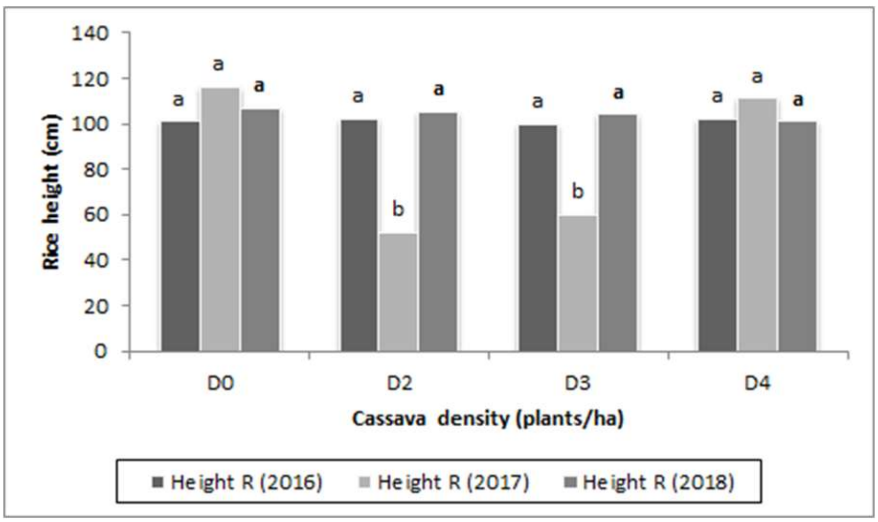
Table 3 shows the rice height according to the different associated cassava densities. There is significant (P=0.005) effect of cassava density on rice height. Rice height ranged from 86.83cm (D2) to 108.08cm (D0).

Table 3. Rice height of the different associated cassava densities

Treatment	Rice Height (cm)
D0	108.08a
D2	86.83b
D3	88.08b
D4	105.00a
GM (cm)	97
CV (%)	18.16
P > F	0.005

a and b are indicating significant mean values in column for a=0.05 with significant difference

However, in detail, Figure 1 shows no significant effect of cassava density on rice height during the cropping cycles of 2016 (P=0.918) and 2018 (P=0.252). Meanwhile, in year 2017, significant ($P<0.0001$) effect was observed with cassava development. Except for D2 and D3, no significant difference was observed across the years. The values observed for D0 were similar to that of D4.



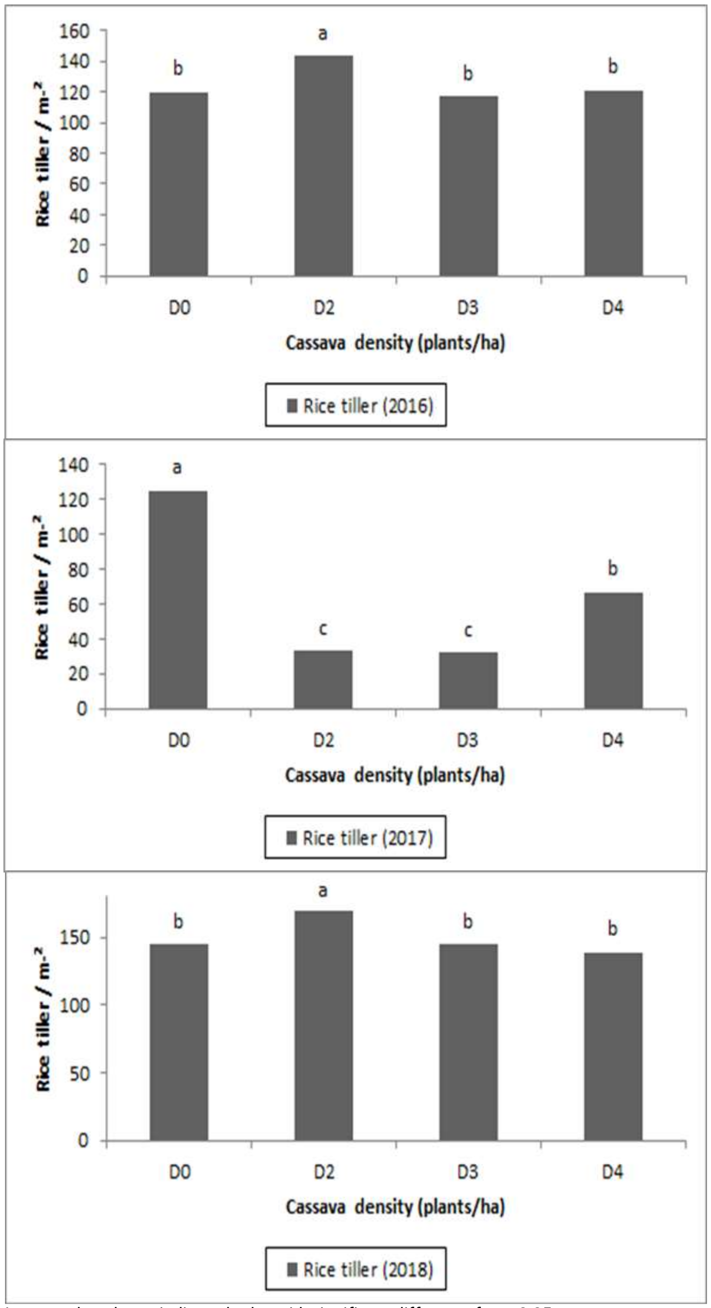
Letters a and b are indicated value with significant difference for a=0.05

Figure 1. Rice height corresponding to different cassava densities

The rice height was negatively impacted by cassava density in the association. This impact was more accentuated over the growing duration of cassava due to cassava growth and soil covering by the canopy. No effect of cassava was observed on rice height during a single year of cropping because of a weak competition of cassava against rice due to the slowness of cassava development (Amanullah et al 2007, Polthanee et al 2007). In the second cropping year, roots competition and sunlight interception for photosynthesis were involved in the interaction of both crops. Yet, Baumann et al (2001a, b) underlined the necessity of a good spatial arrangement between associated crops in order to share the benefits of their interactions (Sinoquet et al 2000, Okonji et al 2012).

Rice Tillering

Figure 2 shows the variation of the number of rice tillers across the cropping seasons according to cassava densities.



Letters a, b and c are indicated value with significant difference for a=0.05

Figure 2. Number of rice tillers every year of cropping with various cassava densities

There is a significant effect of cassava density on rice tillering during the three years of the trial. In 2016, the rice tillering with density D2 (144 tillers/m^2) was clearly different from rice tillering with density D0, D3 and D4 with a probability (P=0.01). The same trend was observed during 2018 while, contrasting with the result observed in 2017: the number of rice tillers of D2 (33 tillers/m^{-2}) and D3 (32 tillers/m^{-2}) were lower significantly than those with densities D0 (125 tillers/m^{-2}) and D4 (67 tillers/m^{-2}). The tillering was negatively impacted by the cassava density in the association. This impact was more accentuated over time (age of cassava plants) due to cassava growth duration and the canopy covering the soil.

In general, the LAI measure for both crops (rice and cassava) decreases with the increasing cassava density. Nevertheless, perfect correlations were established between LAI, rice height and rice grain yield (Konan 2021). Therefore, the rice intercepts more sunlight when the cassava height increases. This assertion is limited for some cassava densities especially for density 5000 plants ha^{-1} as observed during the second rice cycle.

Rice Grain Yield

Table 4 present the rice grain yield according to the associated cassava densities. There was a significant effect of cassava density on rice grain yield (P=0.0003).The highest grain yield was observed for D0, contrasting with the treatments of cassava association. In detail, table 5 shows the rice grain yield according to cassava densities for every cropping year. Significant effects of cassava density were observed in 2017 and 2018, contrasting with 2016. The highest rice yield was observed for D0 in 2017 and 2018, while the lowest rice yield (<0.50t ha^{-1}) was recorded for the crop associations (D2, D3 and D4). However, rice yield increase (1.08–1.09t ha^{-1}) was observed for different densities of cassava in association with the rice in 2018. No significant difference occurred between the mean values of rice yield recorded for D2, D3 and D4.

Table 4. Rice grain yield with different associated cassava densities

Treatment	Rice grain yield (t ha^{-1})
D0	1.78a
D2	0.81b
D3	0.83b
D4	1.06b
GM (t ha^{-1})	1.12
CV (%)	50.71
P > F	0.0003

Letters a and b are indicated value with significant difference for a=0.05

The rice yield was lowest in 2017 when sown under cassava contrasting with the yields of rice sown when planting cassava in 2016 and 2018. Except for the density 5000 cassava plants/ha, this result may be a consequence of sunlight interception as demonstrated by Caldwell et al (1987). Overall, significant effects of cassava density were observed on rice grain yield. The first cropping cycle (2016) was characterized by highest rice yield due to low competition between the associated crops. Indeed, cassava growth rate may induce competition as well as the duration of the rice cycle. However, cassava is a weak competitor against rice due to the slowness of its development (Amanullah et al 2007, Polthanee et al

2007). This assertion is highlighted by the result observed in the second year of cropping (2017) characterized by almost one year old cassava covering young rice plants. In this situation, the rice mono-cropping system was better than the rice/cassava intercropping system. Overall, only the density of 2500 cassava plants per hectare allows substantial rice production in the rice-cassava intercropping system. This is highlighted by Figure 4 which shows the response curve of grain yield according to cassava density in 2017. There is a reduction of rice grain yield with the increase of the associated cassava density. From 4000 cassava plants per hectare (close to D2), there was no more production of rice.

Table 5. Rice grain yield with different associated cassava densities by year

Treatment	Rice grain yield (t ha^{-1})		
	2016	2017	2018
D0	1.75a	1.95a	1.64a
D1	-	-	-
D2	1.33a	0.00b	1.09b
D3	1.34a	0.06b	1.09b
D4	1.70a	0.40b	1.08b
GM (t ha^{-1})	1.50	0.60	1.23
CV (%)	21.34	57.06	11.00
P > F	0.190	<0.0001	0.0002

Means with the same letter among columns are not significantly different

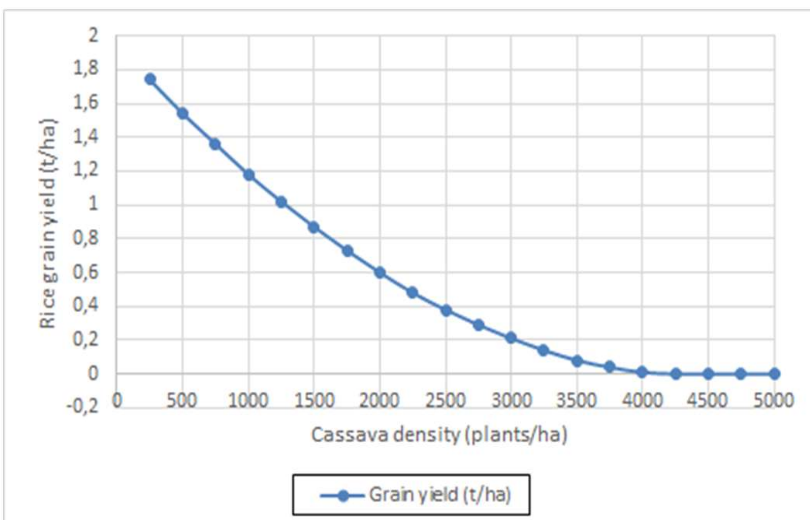


Figure 4. Response curve of rice grain yield versus cassava density in 2017

Treatment Effects on Cassava Yield

Table 6 shows cassava yield annually in 2017 and 2019 according to planting density. There was a significant effect of the treatments on cassava yield. No significant difference was observed between the mean values of yield except for the treatment D1. The harvest recorded in 2019 was lower than that of 2017.Dahniya et al (1994) reported that cassava tuber yield may significantly improve with the increase of planting density even depending on genotype variability. In contrast, the increase of cassava density increased yield but always resulted in rice grain yield decline.

Table 6. Cassava root yield with different cassava density by year

Treatment	Roots cassava yield (t ha^{-1})	
	2017	2019
D1	50.82a	18.55a
D2	36.72b	11.32b
D3	42.41ab	14.05ab
D4	31.67b	13.12b
GM (t ha^{-1})	40.40	14.26
CV (%)	19.64	21.15
P > F	0.03	0.03

Letters a and b are indicated value with significant difference for a=0.05

Competition of Crops

Table 7 shows the relationship between the cassava agro-morphological parameters and the rice grain yield. There is missing data for the plant density 5000 ha^{-1} (D2) characterized by the absence of rice production. In contrast, a significant correlation ($P<0.05$) is observed for 3333 cassava plants per hectare (D3). Indeed, the rice grain yield is negatively correlated ($R=-0.97$) with the stem circumference and the diameter of the tuberous cassava roots, but positively ($R=0.97$) with the number of damaged cassava plants ($P=0.03$). In addition, there is significantly ($P=0.009$) high positive correlation (0.99) between the cassava height and the rice grain yield when the cassava is planted at the density of 2500 plants per hectare (D4). To some extent ($\alpha=0.10$), tuber weight can induce a negative correlation ($R=-0.91$) with rice grain yield as observed in D3. This is explained by greater availability of nutrients for rice and cassava to increase their potential yield with the density of 2500 cassava plants per hectare.

This assertion is in line with Akonji et al (2007) when reporting that a low cassava density allow more availability of sunlight and nutrients. Thus, low rice grain yield caused by strongest competition was found in 3333 and 5000 cassava plants per hectare and 10% of rice grain yield reduction was observed. The competition between rice and cassava was further highlighted by the results of the principal component analysis (Table 8 and Table 9), which shows the impact of cassava agro-morphological parameters on rice grain yield. Therefore, rice-cassava intercropping is recommended with 2500 plants/ha cassava in alternate years for sustaining rice-cassava agro-system in the west Côte d'Ivoire.

Table 3. Canopy circumference (cm) as influenced by intra-row spacing at 25-31WAT

Variables		Cassava Densities					
		5000 plants ha^{-1} (D2)		3333 plants ha^{-1} (D3)		2500 plants ha^{-1} (D4)	
		R	P > |r|	R	P > |r|	R	P > |r|
Rice grain yield (t ha^{-1})	Cas. survival rate (2016)	.	.	0.78	0.21	-0.71	0.28
	Cas. survival rate (2017)	.	.	0.46	0.53	0.01	0.98
	1Plt/cutting	.	.	-0.91	0.08	0.22	0.77
	2Plts/cutting	.	.	0.58	0.41	-0.28	0.71
	3Plts/cutting	.	.	0.07	0.92	0.27	0.72
	Cas. height	.	.	-0.49	0.51	0.99	0.009
	LAI-cas.	.	.	-0.49	0.51	0.16	0.83
	Stem circ	.	.	-0.97	0.03	0.88	0.11
	Root diameter	.	.	-0.97	0.03	0.82	0.17
	Nb of Cas. plt damaged	.	.	0.97	0.03	-0.85	0.14
	Root yield	.	.	-0.54	0.40	0.71	0.28
	Root weight /cutting	.	.	-0.91	0.08	0.78	0.21

Cas: Cassava; Plt: Plant; cir: circumference; Nb: Number

Table 8. Matrix of impact of cassava agro-morphological parameters on rice grain yield

Component Contribution	Factor 1	Factor 2
Cassava density	0,10	0,69
1Plant/cutting	0,16	0,17
2Plants/cutting	0,16	0,03
3Plants and more/cutting	0,15	0,01
Cassava height	0,21	0,05
LAI–cassava	0,21	0,05
Eigen cumulative value (%)	74,92	10,73

Table 9. Matrix of factor-variables (impact of cassava agro-morphological parameters on rice grain yield)

Variables	Factor-variable Correlation	
	Factor 1	Factor 2
Cassava density	-0.69	-0.67
1Plant/cutting	-0.86	0.33
2 Plants/cutting	-0.84	-0.14
3 Plants and more/cutting	-0.81	-0.07
Cassava height	-0.97	0.19
LAI-cassava	-0.98	0.17

Performance of the Rice/Cassava Intercropping

Table 8 gives the values of the intercropping performance index according to the LER and ATER parameters during two respective cassava cycles (1 and 2). All the observed values were low (<1) ranging from 0.56–0.97 (LER) and from 0.61–0.83 (ATER). Nevertheless, the highest values were observed for D3 or D4 for both parameters.

The value of LER and ATER showed that the rice-cassava intercropping has lower performance than the rice mono-cropping system. Crop competition contributed to this result. The second cropping cycle of rice was negatively impacted by the one year old cassava covering the young rice plants. This situation induced yield loss due to the low rate of sunlight interception by the young rice plants. Otherwise, the ATER calculation points to the unsuitability of such crop associations. Indeed, the cassava cycle was equivalent to two cropping seasons (wet season) while, the rice cycle duration was limited to one cropping season. In this line, we assume that cassava yield should be divided by both seasons as two seasons of rice cropping. According to this approach, LER and ATER values ranged from 1.19–1.35 (LER) supporting this intercropping practice and indicating treatment D3 as the best despite of the low values of ATER (0.86–0.88). On the other hand, one can use the average rice grain yield during the first cassava cycle (two cropping seasons) for LER values of 1.16–1.35 and ATER values of 0.85–0.88. Whatever the method, it appeared that the rice-cassava intercropping has better performance than rice and cassava mono-cropping respectively. It is necessary to explore the determination methods of rice-cassava intercropping performance in future studies.

Table 10. Values of the performance index (LER and ATER) of the rice/cassava intercropping

	Cassava cycle 1				Cassava cycle 2			
	2016		2017		2018		2019	
	LER	ATER	LER	ATER	LER	ATER	LER	ATER
D0	-	-	-		-	-	-	-
D1	-	-	-		-	-	-	-
D2	0.76	0.76	0.56	0.61	0.66	0.66	0.61	0.61
D3	0.77	0.77	0.86	0.83	0.66	0.66	0.76	0.76
D4	0.97	0.97	0.83	0.76	0.66	0.66	0.71	0.71
GM	0.83	0.83	0.75	0.73	0.66	0.66	0.69	0.69

GM: Grand mean, LER: Land Equivalent Ratio; ATER: Use space-time ratio; - : not determined

The result observed during this current study support crop diversity in an agro-system especially, for rice cropping regarding soil enrichment with N and P in addition to the supplemental gross production as demonstrated by the LER calculation. However, crop cycle duration may have contributed to the values of LER recorded. The ATER was calculated taking into consideration the cropping cycle duration (Aasim et al 2008). The density D3 (3333 plants ha^{-1}) still appeared as the best time-space option in the studied agro-system. This observation reinforces the suitability of D3 for rice-cassava intercropping in the west Côte d'Ivoire. However, a slight positive yield was observed for D4 against D3 during the study. This fact may raise economic considerations taking into account the income equivalent ratio (Hiebsch and McCollum 1987). Unfortunately, this parameter was not explored during the current study nor was the light transmission ratio (Willey 1979).

Therefore, we can recommend D3 as the optimal density of rice-cassava cropping in west Côte d'Ivoire and recommend future studies for strengthening knowledge about the method of calculating rice-cassava intercropping performance.

CONCLUSION

The study showed a significant effect of cassava density on the vegetative development of each crop. The rice grain yield decreased with the association of cassava while, cassava roots yield increased with rice as a companion crop. However, the optimum cassava density for the highest yield of rice was 2500 plants ha^{-1} (4mx1m) while the second planting of rice did not survive with 5000 cassava plants/ha. A density of 3333 (3mx1m) cassava plants/ha, was the suitable rice-cassava intercropping density for a more efficient land use ratio. Future studies will be necessary to reinforce knowledge on the determination methods of rice-cassava intercropping performance (ATER calculation method).

REFERENCES

Aasim M, Muhammad EV & Karim A. 2008. Yield and competition indices of intercropping cotton (*Gossypium hirsutum* L.) using different planting patterns. *Ankara Universitesi Ziraat Fakultesi* 14(4):326-333

Amanullah MM, Kailasam C, Safiullah AM, Selvam S & Sivakumar K. 2007. Crop simulation growth model in cassava. *Research Journal of Agriculture of Biological Science* 3(4): 255-259

Bahan F, Keli J, Yao-Kouame A, Gbakatchetche H, Mahyao A, Bouet A & Camara M. 2012. Caractérisation des associations culturales à base de riz (*Oryza* sp): cas du Centre-Ouest forestier de la Côte d'Ivoire. Journal of Applied Biosciences 56:4118-4132

Bailey SW, Brindley GW, Johns WD, Martin RT & Ross M. 1971. Summary of national and international recommendations on clay mineral nomenclature. *Clays and clay minerals* 19:129-132

Baumann DT, Bastiaans L & Kropff MJ. 2001a. Competition and crop performance in a leek–celery intercropping system. Crop Science 41(3):764-774

Baumann DT, Bastiaans L & Kropff MJ. 2001b**.** Effects of intercropping on growth and reproductive capacity of late emerging *Senecio vulgaris* L., with special reference to competition for light. *Annals of Botany* 87(2):209-217

Bonneau M and Souchier B. 1994. Pédologie 2. Constituants et propriétés du sol (2nd edn). Masson, Paris, France

Bremner JM. 1996. Nitrogen-total. In Sparks DL, Page AL, Helmke PA, Loeppert RH, Soltanpour PN, Tabatabai MA, Johnston CT & Summer ME (eds) *Methods of Soil Analysis: Part 3 Chemical methods* (pp1085-1121). Soil Science Society of America and American Society of Agronomy, Madison, USA

Brindley GW. 1966. Discussions and recommendations concerning the nomenclature of clay minerals and related phyllosilicates. *Clays and Clay Minerals* 14:27-34

Caldwell MM. 1987. Plant architecture and resource competition. In Schulze ED and Zwolfer H (eds) *Ecological Studies.* Potentials and Limitations of Ecosystem Analysis, Springer, Berlin

Dahniya MT, Akoroda MO, Alvarez MN, Kaindaneh PM, Ambe-Tumanteh J, Okeke JE & Jalloh a. 1994. Development and dissemination of appropriate root crops packages to farmers in Africa. *Acta Horticulturae* 380(1):2-29

FAO. 2016. Production/consommation du riz en Côte d'Ivoire. FAOSTAT en ligne. (Voir http://faostat.fao. org). Rome. (Consulté le 10 juin 2018)

Hiebsch CK and McCollum RE. 1987. Area-X-Time Equivalency Ratio: A Method for Evaluating the Productivity of Intercrops. *Agronomy Journal* 79:15-22

Makinde EA and Ayoola OT. 2008. Residual influence of early season crop fertilization and cropping system on growth and yield of cassava. *American Journal of Agricultural and Biological Science* 3(4):712-715

N'Da KL. 2002. Etude des associations culturales traditionnelles:cas de l'association riz-maïs à Dikodougou. Mémoire de DUT, URES de Korhogo, Université de Bouaké, Côte d'Ivoire (p26)

N'zué B, Zohouri PG & et Yapi-Gnaoré V. 2005. Bien cultiver le manioc en Côte d'Ivoire, Centre national de recherche agronomique (CNRA)(pp1-4)

Konan KU. 2021. Fertilité du sol et rendement du binôme riz-manioc dans les systèmes de culture à base de riz en zone semi-montagneuse de l'Ouest Côte d'Ivoire : amélioration de l'association et de la rotation riz-manioc. Mémoire de thèse de Doctorat en pédologie. Université Félix Houphouët-Boigny de Cocody Abidjan (Côte d'Ivoire) (p138)

Polthanee A, Wanapat S, Wanapat M & Wachirapokorn C. 2007. Cassava-Legumes inter-cropping: A potential food-feed system for dairy farmers. *Proceedings from the International Workshop on Current Research and Development on Use of Cassava as Animal Feed*, 9 January 2007, Khon Kaen, Thailand. Khon Kaen University

ONDR. 2017. Statistiques et production. Disponible à http://www.ondr.ci/sndr_20122020.php.Consultéle02/01/2016

Okonji JC, Emmanuel OA, Okeleye AK, Oyekanmi AA, Aderibigbe GS, & Sakariyawo OS. 2012. Upland rice based intercropping system among farmers in selected villages in Ogun State in South west of Nigeria. *Journal of Agricultural Extension and Rural Development* 4(17):456-464

Page AL, Miller RH & Keeney DR. 1982. Methods of Soil Analysis Part 2: Chemical and Microbial Properties (2nd edn). American Society of Agronomy, Inc. and Soil Science Society of America Inc., Madison, Wisconsin, USA

Sinoquet H, Rakocevic M & Varlet-Grancher C. 2000. Comparison of models for daily light partitioning in multispecies canopies. *Agricultural and Forest Meteorology* 101(4):251-263

Vendrame PRS, Brito OR, Martins ES, Quantin C & Guimaraes MF. 2013. Acidity control in Latosols under long-term pastures in the Cerrado region, Brazil. *Soil Research* 51(4)253-261

Walkley A and Black IA. 1934. An Examination of the Degtjareff Method for Determining Soil Organic Matter, and a Proposed Modification of the Chromic Acid Titration Method. *Soil Science* 37(1):29-38

Willey RW. 1979. Intercropping-Its Importance and Its Research Needs. Part 1. Competition and Yield Advantages. *Field Crops Abstr* 32:1-10