Journal of Food and Nutrition Research, 2021, Vol. 9, No. 5, 251-257
Available online at http://pubs.sciepub.com/jfnr/9/5/2
Published by Science and Education Publishing
DOI:10.12691/jfnr-9-5-2

Improvement of Intercropping Performance Assessment in a System with Difference of Crops' Cycle Durations: Calculation Methods for Rice-cassava Association

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Received April 02, 2021; Revised May 03, 2021; Accepted May 10, 2021

Abstract Crop performance evaluation in intercropping involving booth crops with different cropping cycle durations is still a concern for agronomic research while farmers already adopted this agro-system in spite of yield decreasing of one of the component. Agronomic trial involving rice-cassava intercropping with different densities of cassava planting was undertaken in western Côte d'Ivoire to determine most reliable parameters for performance index calculation comparing the conventional to new proposed methods. In a Fisher design, number of root/plant, cassava yield, cassava yield/2 rice cycles, 1000 rice grain weight, and rice grain yield were collected for exploring their reliability on global yield determination. Area Time Equivalent Ratio (ATER) and Crop Performance Ratio Time corrected were calculated as conventional method of performance index assessment while, average yield of cassava for two cycle of rice (ATER1) and the mean for both cropping cycles of rice (ATER2) were proposed as new methods. Except the variation of yield in single cropping, no significant effect of cassava planting density was recorded in global production and ATER value overlapped the threshold value of 1 in some extend. Only calculated yield were reliable for global production pointing out ATER1 as the most consistent method for rice-cassava intercropping performance determination. Rice grain yield and half of cassava yield calculated on basis of two rice cropping cycle were revealed as the most reliable parameters for ATER calculation highlighting such method viability for intercropping performance assessment when involving two crops with different cycle durations.

Keywords: *global production, crop cycle duration, intercropping performance, Area Time Equivalent Ratio*

Cite This Article: Konan Kouassi Urbain, Koné Brahima, Konan Kouamé Firmin, Keli Zagbahi Jules, Bouet Alphonse, and Yao-Kouamé Albert, "Improvement of Intercropping Performance Assessment in a System with Difference of Crops' Cycle Durations: Calculation Methods for Rice-cassava Association." *Journal of Food and Nutrition Research*, vol. 9, no. 5 (2021): 251-257. doi: 10.12691/jfnr-9-5-2.

1. Introduction

The improvement of agricultural sustainability favors the maintenance of the intercropping systems [1]. This practice has been acclaimed internationally as the most reliable approach to safeguard the sustainability of vegetable production [2,3,4]. Worldwide, including Côte d'Ivoire, intercropping was practiced since antiquity and continuous to be adopted by farmers in particular, for upland rice production mixing with cassava crop. But the gape recorded in rice production requires analyze of this production system, while, existing index of performance assessment missed accuracy when intercropping includes crops with different cycle durations [5,6]. Area-Time Equivalent Ratio (ATER) proposed to solve this problem is considered to be underestimating the advantage of intercropping [1]. Hence, crop performance ratio "time corrected" concept was initiated by [7] but, its' adoption is still limited [8]. Therefore, there is a lack of fitting method for assessing intercropping performance involving crops with difference in cycle durations. In this line, Konan *et al*. (unpublished) also proposed two new methods for rice-cassava intercropping in western Côte d'Ivoire involving upland rice and cassava. Rationalizing yield production according to the shortest cycle duration of one of the crops and/or using the total production within the longest cycle duration were deemed to be inclusive in intercropping performance.

The current paper is volunteer to assess the accuracy of new methods of intercropping performance determination compared to the conventional methods.

It aims to i) High light an optimum density for Global net production in rice-cassava intercropping; ii) identifying yields and yield components relevant to global net production in intercropping system and iii) identify the most accurate method for intercropping performance calculation while involving crops with different cycle durations. Ultimately, this study should propose the better performance appreciation method for rice-cassava intercropping system.

2. Material and Methods

2.1. Experimental Site

The study was carried out at the CNRA research station in Man, west of the Côte d'Ivoire (N 070 20'58'', W 070 36'05'' and 337 m in elevation). A monomodal rainfall pattern characterized the site. A five years old fallow was the initial vegetation *dominated* by *Panicum maximum*. Enriched coarse particles (> 50 p.c.) were observed within 20 and 60 cm depth in a sandy-clay loam topsoil (0-20 cm) and a clay-sandy subsoil (20-60 cm).

2.2. Genetic Material

The Genetic material was consisting of improved short-cycle (105 Days) rice variety named IDSA 10 (105-day seed-to-maturity cycle), with a potential yield of 4 t ha^{-1} and a height at maturity of 110-115 cm. On the other hand, the improved erected cassava variety named BOCOU 5, characterized by 12 months duration of cycle with a potential yield estimated to be 50 t ha^{-1}.

2.3. Experimental Layout

The test was conducted in a randomized complete blocks design, with 5 treatments and 4 replications (blocks). The factor studied is the density of cassava associated with rice. Each treatment was set in a micro-plot of 6 m × 10 m with 1 m as inter-plot space in a block (replication). Four replications spaced by 2 m were considered for a total of 20 micro-plots. The treatments are as follows:

Table 1. Description of the treatments

TREATMENT	RICE SOWING	CASSAVA PLANTING	SYSTEM
D0	0.20 m x 0.20 m	0	Rice monocropping
D1	0	1 m x 1 m	Cassava monocropping
D2	0.20 m x 0.20 m	2 m x 1 m	intercropping
D3	0.20 m x 0.20 m	3 m x 1 m	intercropping
D4	0.20 m x 0.20 m	4 m x 1 m	intercropping

After land preparation (clearing and collection of debris), a shallow plowing (0-20 cm) of soil was carried out. The sowing of the rice was synchronized with the planting of the cassava, in the first year from the beginning of the rainy season. Two successive rice cropping were carried out for a single cassava cycle. A basic fertilizer, NPK (10%, 22%, 22%) was incorporated into the soil before sowing at the rate of 300 kg / ha for each micro-plot. Direct sowing in a 5-seed pocket was made for the rice and a 20 cm cassava cutting was planted burring in 5 cm depth in soil. During rice growing, 100 kg/ha of 46% N pearl urea were applied splitting the rate: 50 kg at the beginning of tillering stage and 50 kg at the boosting stage.

3. Data Collection

3.1. Rice Data Collection

Excluding rice yield parameters observed in a squares meter ($1m^2$), the main parameters collected for crop performance index calculation were: (i) the date of 50% flowering observed in the entire plot (physiological maturity of rice) and (ii) the harvest period as cropping cycle during. (iii) rice was harvested in $60m^2$ and sundried before threshing and weighing. The grain yield (GY) was obtained for 14% moisture content in the grain.

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

$$H = Humidity\ rate$$

During the calculation of crop performance index, GY were considered for each rice cropping cycle or as average of two cropping cycles of cassava knowing that single cassava cropping cycle covered two harvest of rice.

3.2. Cassava Data Collection

Observations were done in the useful plot corresponding to the exclusion of two lines of border.

The diameter of the tuberous roots was measured coupled with the fresh weight for each micro-plot. Cassava root yield (CR) was determined accordingly to plot size. For crop performance calculation, CR was considered for each cassava cycle or divided by to (2) knowing that CR was corresponding to two rice cropping cycles.

4. Methods of Crop Performance Calculation

4.1. Global Net Production of the System

This is the reference parameter for crop performance calculation according to the newly proposed methods.

The global net production (GP) of the system was calculated according to the yields of rice and cassava using the method of [9] respectively:

$$GP = \frac{\sum intercropped\ crop\ yields}{\sum Yields\ of\ sole\ crops} \quad (2)$$

Therefore, we used:

$$GP = \frac{\left(\begin{array}{l} Yield\ of\ rice\ intercropped \\ +\ yield\ of\ cassava\ intercropped \end{array}\right)}{\left(\begin{array}{l} Yield\ of\ Rice\ sole \\ +Yield\ of\ Cassava\ sole \end{array}\right)}$$

Conventional methods

Land Equivalent Ratio was defined by [10] as:

$$LER = \frac{Yield\ of\ Rice\ in\ the\ intercrop}{Yield\ of\ Rice\ in\ the\ monocrop} + \frac{Yield\ of\ Cassava in\ the\ intercrop}{Yield\ of\ Cassava in\ the\ monocrop} \quad (3)$$

Area Time Equivalent Ratio (ATER) was defined by [11] as:

$$ATER = \left[(GYr\ x\ tr)+(CYr\ x\ tc)\right]/T \quad (4)$$

Ryr and Ryc = Relatives yields of rice and cassava, respectively; tr and tc = maturity periods of rice and cassava, respectively. T is the duration of the intercropping system.

Crop Performance Ratio Time corrected (CPRT) was defined by [7] as:

$$CPRT = (Yir + Yic)*tc/(Pir*Ysr*tc + Pic*Ysc*tr) \quad (5)$$

Where Yir and Yic refer respectively to the yields of rice and cassava in intercropping; Ysr and Ysc represent respectively to the yields of rice and cassava in single cropping; Pir and Pic = proportional sown area of rice and cassava in the intercrop; tr and tc = Rice and Cassava cycle duration.

4.2. Proposed New Methods

Performance index determination method 1

As cassava cycle duration was observed over two cropping seasons, we assume more accuracy for average season yield while cropping with rainfed rice for ATER calculation:

$$ATER\ 1 = \left(\frac{Yield\ of\ Rice\ in\ the\ intercrop}{Yield\ of\ Rice\ in\ the\ monocrop}*tr + \frac{Half\ Yield\ of\ Cassava\ in\ the\ intercrop}{Half\ Yield\ of\ Cassava\ in\ the\ monocrop}*tc \right)/\mathrm{T} \quad (6)$$

Tr and Tc: rice and cassava cycle duration;

T: intercropping system cycle duration

Performance index determination method 2

One cassava cycle was observed for two harvests of rice requiring time adjustment of rice yield as the mean for both cropping cycles:

$$ATER\ 2 = \left(\frac{Mean\ RiceYield\ in\ the\ intercrop}{Mean\ RiceYield\ in\ the\ monocrop}*tr + \frac{Yield\ of\ Cassava\ in\ the\ intercrop}{Yield\ of\ Cassava\ in\ the\ monocrop}*tc \right)/T \quad (7)$$

4.3. Statistical Analysis

Analyzes of variances were performed using crops' yields according to respective density. The same was done for ATER to explore density effect on intercropping performance using SAS version 9 software at the 5% threshold level. STATISTICA version 7.1 software was also used to perform reliability in a way to identify crop parameters (haft yield of cassava, average yield of rice, rice annual yield, cassava yield, yield components…) to be considered in the method of performance index of calculation. This reliability was assessed regarding to the global net production [9].

5. Results

5.1. Rice Grain Yield

Table 2 shows the mean values of rice grain yield according to cassava densities for every cropping cycle. Significant effect of cassava density is observed in 2017 and 2018, contrasting 2016. Highest rice yield is observed for D0 in 2017 and 2018 while, lowest rice yield (<0.50 t ha^{-1}) accounted for the treatments D2, D3 and D4 characterized by crops' association. However, rice yield increase (1.08 – 1.09 t ha^{-1}) is observed for different densities of cassava in association with the rice in 2018. No significant difference occurred between the mean values of rice recorded for D2, D3 and D4.

Table 2. Average rice grain yield of different associated cassava densities by cropping season

	Rice grain yield (t/ha)		
TREAT	**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)	1.50	0.60	1.23
CV (%)	21.34	57.06	11.00
P > F	0.190	< 0.0001	0.0002

Mean values followed by the same letter in the same column are not significantly different at P < 0.05.
-: missing data.

5.2. Treatment Effect on Cassava Yield

Table 3 presents mean values of cassava yield according to cassava densities for every cropping cycle.

There is a significant effect of cassava density on cassava yield (P < 0.05), with high yield in 2017.

Table 3. Roots cassava yield of different cassava density by season

	Roots cassava yield (t/ha)	
	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)	40.40	14.26
CV (%)	19.64	21.15
P > F	0.03	0.03

Mean values followed by the same letter in the same column are not significantly different at P < 0.05.

5.3. Treatment Effect on Global Net Production and Other Yield Parameters

No significant effect of cassava planting density was observed in the global net production in Table 4. Nevertheless, the mean values observed are statistically similar:

Table 4. Global net production by cropping density according to both cycles of cassava

	Global net production (RYT)	
	2017	**2019**
D1	--	--
D2	0.73a	0.62a
D3	0.79a	0.69a
D4	0.79a	0.71a
GM (t/ha)	0.77	0.67
CV (%)	27.09	27.14
P > F	0.818	0.776

Mean values followed by the same letter in the same column are not significantly different at P < 0.05.

There is significant effect of cassava planting density on rice grain yield determined as average corresponding to one cropping of cassava (Table 5). There is also significant difference between observed rice yields while no difference is observed when associated with cassava independently to cassava density. In some extend (α= 0. 10), half yield of cassava is showing significant effect of planting density with no difference between the observed mean values.

Table 5. Proposed variables for performance index calculation according to cropping density

Cropping density	Explored variables for performance index				
	Half yield of cassava (t/ha)	Mean grain yield/cassava cycle (t/ha)	Root mean weight (kg)	Root number/Plant	Thousand grain weight (g)
D0	--	1.63a	--	--	37.06a
D1	17.34a	--	1.14a	8.85a	--
D2	12.01a	0.88b	1.29a	9.89a	36.62a
D3	14.12a	0.90b	1.39a	9.24a	35.74a
D4	11.20a	1.07b	1.49a	10.02a	36.75a
GM	13.67	1.12	1.33	9.5	36.54
CV (%)	53.98	18.50	74.85	20.29	4.58
P > F	0.096	< 0.0001	0.910	0.584	0.267

Mean values followed by the same letter in the same column are not significantly different at P < 0.05.

The other studied parameters show no significant effect of cassava planting density.

5.4. Performance of the Rice/Cassava Intercropping

Conventional method: ATER values by season

Table 6 shows the values of the intercropping performance index according to the ATER for each cropping cycle of cassava (cycle 1 and cycle 2) regarding to cassava planting density. There is no significant effect of the planting density on ATER index and no difference is observed between the mean values.

Table 6. Area Time Equivalent Ratio values according to two cassava cycle

	Area Time Equivalent Ratio	
	Cassava cycle 1	**Cassava cycle 2**
D2	0.47a	0.40a
D3	0.56a	0.48a
D4	0,51a	0.46a
GM	0.51	0.45
CV (%)	63.75	67.53
P > F	0.862	0.869

All the values observed are low (<1) ranging from 0.47 – 0.56 (cassava cycle 1) and from 0.40 – 0.48 (cassava cycle 2).

Method 1: cassava yield divided between both cycle

Table 7 presents ATER index values of rice-cassava intercropping according to the densities of cassava for each cassava cycle. There is no significant effect of cassava density on intercropping performance index. All the values of ATER are low (< 1).

Table 7. ATER values of rice-cassava intercropping in function cassava densities

	Area Time Equivalent Ratio	
	Cassava cycle 1	**Cassava cycle 2**
D2	0.83a	0.81a
D3	0.95a	0.96a
D4	0.79a	0.91a
GM	0.86	0.89
CV (%)	24.65	23.03
P > F	0.307	0.581

More stable value accounts for D3 (0.95 – 0.96) while they varied from 0.79 to 0.91 for D4.

Method 2: Using the mean value of rice grain yield during a cassava cycle

Table 8 give the values of the intercropping performance index according to the ATER parameters during both respective cassava cycles (1 and 2). No significant effect of cassava density is observed on intercropping performance index.

Table 8. ATER values of different cassava densities

	Area Time Equivalent Ratio	
	Cassava cycle 1	**Cassava cycle 2**
D2	0.91a	0.81a
D3	1.03a	0.97a
D4	0.91a	0.91a
GM	0.95	0.89
CV (%)	21.86	23.03
P > F	0.631	0.581

However, ATER value may reach over 1 as observed in cassava cycle 1 for D3 while, the other values are observed in the range of 0.81 – 0.91.

5.5. Crop Performance Ratio Time Corrected (CPRT)

In some extend (α= 0.10), there is significant effect of cassava density on CPRT during cassava cycle 1. Anyway, no significant difference is observed between the mean values independently to cassava cycle. The values observed are ranging from 0.32 – 0.58 far below the critical value of 1.

Table 9. CPRT values of different cassava densities

	Crop Performance Ratio Time corrected	
	Cassava cycle 1	**Cassava cycle 2**
D2	0.39a	0.32a
D3	0.63a	0.49a
D4	0.58a	0.52a
GM	0.53	0.45
CV (%)	25.65	28.87
P > F	0.07	0.121

5.6. Indication of Fitting Parameters for Calculation

Table 10, Table 11 and Table 12 present different reliable parameters for global production. The parameters used for calculation of conventional and new proposed method are tested. Table 10 show a standardized α of 0.68 and low values of α for all the studied parameters when they are delated from the test respectively. Lowest values are observed for rice grain yield (0.50), cassava yield (0.36) and half cassava yield (0.22). Nevertheless, α-standardized remains low than 0.70 likely for the mean of correlation between questions (0.58). Therefore, the tested parameters are inducing a poor reliability for the global production of the cropping system. .

Table 10. Reliable parameters for global production

Variables	Mean= 86.69; Ec-T.= 22.82; N active: 24 α- Cronbach: 0.59 ; α- Standardized : 0.68 Correl. inter-quest.: 0.58		
	Standard deviation if Cancel	Correlation Qst. Tot	Alpha if cancel
Rice grain yield	21.72	0.87	0.58
Cassava yield	8.87	0.94	0.36
Half cassava yield	15.54	0.98	0.22
Mean grain yield/cassava cycle	22.44	-0.43	0.62
Root mean weight	21.43	0.92	0.56
Root number/Plant	21.57	0.35	0.58
Thousand grain weight	22.82	-0.34	0.64

In turn, high value of inter question correlation (0.89) is observed (Table 11) for different yields (rice and cassava) calculation but α-standardized is low than 0.70. In spite of the reliability of cassava yield and half cassava yield, the overall reliability is poor.

Table 11. Reliable yield parameter for global production

Variables	Mean=39.09 Ec-T.=21.61 N actifve24 α Cronbach : 0.63 α-Standardized : 0.55 Correl. inter-quest.: 0.89		
	Standard deviation if cancel	Correlation Qst. Tot	Alpha if Cancel
Rice grain yield	20.53	0.85	0.66
Cassava yield	7.39	0.99	0.18
Half cassava yield	14.27	0.99	0.10
Mean grain yield/cassava cycle	21.26	-0.49	0.71

In Table 12 we have the result of a short list of tested parameters as rice yield, cassava yield and half cassava yield. There are high values of α- standardized (0.97) and inter question correlation value (1):

Table 12. Very Reliable yield parameter for global production

Variables	Mean.=38.14 E-T.=21.72; N active:24 α-Cronbach: 0.7123 ; α- Standardized : 0.97 Correl. inter-quest.: 1		
	Standard deviation if Cancel	Correlation Qst. Tot	Alpha if Cancel
Rice grain yield	20.65	0.85	0.88
Cassava yield	7.50	0.99	0.29
Half cassava yield	14.38	0.99	0.16

All the tested parameters induce lower values of α-standardized respectively than the global α-standardized if they are excluded from the list asserting their reliability for the global production of the system.

6. Discussion

6.1. Mitigated Impact of Planting Density as Global Production Factor

Planting density of cassava has significantly affected rice yield and cassava yield respectively. Excluding the mono-cropping (D0 and D1), the yields recorded in the association of rice-cassava were not significantly different except a leaser increased of cassava yield in D3. A significant effect of crop planting density was also underlining a declining of the yields of associated crops especially during subsequence cropping seasons most characterized by yield declining for cassava. Similar results were observed for global net production and different cropping performance index. It was likely that the planting density of cassava was not a significant factor of the system production regarding to global net production. This result reinforce the miss understanding of farm size productivity in agriculture [12].

Indeed, the relationship between the factors of agricultural production is complexed when considering the soil type, agro-climatic conditions, and the transaction costs of production factors, the technology involved, and the available labour force as a short list when we are considering that specific agricultural services can account for a wide range of practices [13].

In the light of the lack of significant difference between the mean values of global production (GP), we can assume that genetic performance of crops and environment factors (soil and agro-climate) as pointed out by [14] may have prevailing impact on the system productivity than the planting density. Nevertheless, this parameter has significant effect on the yield in sole cropping. Practical consequence of such results required investigation of genetic and environment test (G ×E) for sound recommendation when improving cropping systems. Of course, optimum planting density may have variability according to the environment and management at field scale [15,16]. Therefore, the low value (0.68) of α-standardized observed in Table 10 was so justified knowing that most the contributors considered were accounting for yield parameters while the yields were highly (>0.80) correlated with question rose respectively. Negative correlation was observed for mean rice grain yield by cassava cycle (Table 11) excluding this parameter for global net production assessment as well as the yield parameters and cassava planting density.

6.2. Importance of Global Production in a Cropping System

Except the slight significant effect (P< 0.07) of cassava planting density on CPRT during the first cropping cycle of cassava, none of such observation was observed while ATER may reach 1.03 (Table 8). Therefore, cropping system performance may have slightly increased the production in rice/cassava when excluding the effect of cassava planting density for ATER calculation. Despite of good correlation observed between yield and land equivalent ratio [17] and time duration adoption in CPRT calculation, ATER seem to be more consistence for crop performance evaluation in rice-cassava associations when considering the mean of rice grain yield (2 cycles) for a single cropping cycle of cassava as assumed by Konan *et al.* (unpublished). This method of rice yield calculation underlined the period (time) of cropping on the basis of the respective cropping cycle duration as asserted by [18]. The density D3 (3333 plants/ha) appeared as the best time-space valorizing in the studied agro-system (West Cote d'Ivoire) pointing out the sensitive economic consideration often evolved [11] when recording the global production. This concept is very important because it is relevant to physiological and economical aspect. Indeed, it include the gross primary production (GPP) and net primary production [19] that should be measured at the ecosystem scale over relatively long time intervals [20]. Global net production (GNP) may help to assess the income of agricultural practice in field scale during a short period. It reflects carbon valorization, light transmission efficiency [10] and cash return to farmer [21]. Off course, among the advantages of the intercropping system is the increase in productivity per area unit [22] as reflected by GP. However, no increase of cassava yield was observed (Table 3) as asserted by [23] but rice yield was complementary.

6.3. Sound Data for Rice/Cassava Performance Index Calculation

Global net production of a cropping system was underlined by the current study as the central data of for assessing its performance. Off course, GP may have more importance for a farmer in subsistence agriculture because of food need. In contrast, agronomist may be dubitative when considering main crop and secondary crop. Overall, GP concept may simplified intercropping performance assessment regarding to the lack of difference between the observed values in a manner to minimize the advocated comparison between the performance of the intercrops to that of the component sole crop using [24,25]. However, its consistence may be limited by the lack of consideration of seed or biomass yields [1], likewise by resource use and other attributes demonstrated by [26]. Nevertheless, Intercropping is practiced with the sole aim of maximizing plant cooperation for maximum crop yield [27] as illustrated by GP.

Except the slight significant effect (P < 0.07) of cassava planting density on CPRT during the first cropping cycle of cassava, none of such observation was observed while ATER may reach 1.03 (Table 8). Therefore, cropping system performance may have slightly increased the global production in rice/cassava when excluding the effect of cassava planting density as illustrated by ATER calculation. Regarding to the pessimistic assertion of [1] stating that ATER underestimated the advantage of intercropping when component crops differ in growth duration, we may except more benefit in current crops association. ATER index was deemed to have better and justifiable application in humid tropical areas where there is continuous growing season.

Yet, [28] already applied ATER to analyze yield of a cassava (Manihot esculenta)/sorghum (Sorghum bicolor) intercrop and found positive benefits for intercropping even though ATER adjusted intercropping benefits. However, Rice grain yield harvested by rice cycle and cassava yield by cassava cycle were revealed reliable for global production likewise the half cassava yield calculated for booth rice cycles according to the result showed in Table 12. Therefore, the current study confirmed that conventional method of ATER calculation [equation 6] using the yields of different crops respectively [11] is acceptable for crop performance calculation in rice/cassava association. However, half cassava yield as calculation parameter was more consistence for ATER calculation referring to global production because of lowest α-standardized induced when excluding this parameter. In this line, the new proposed method of ATER calculation the most recommended method when associating two crops with different cropping duration.

7. Conclusion

The study revealed limited effect of cropping density on global production in crops association while very significant in sole cropping. The most significant finding was relevant to the simplified method involving crop cycle duration in crop performance assessment during intercropping of two crops with different cycle durations. ATER was pointed out as the most consistent index when using the half of yield of the crop with longest cycle duration despite of some consistence of the conventional method.

Conflicts of Interest

The author declares no conflicts of interest.

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