Simulation of the Growth and Leaf Dynamic in Quality Protein Maize and Soybean Intercropping Under the Southwestern Savannah Conditions of DR Congo

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Abstract

This paper contributes to the development of methodological tools to understand and predict the functioning of cereal-legume crop associations through mathematical approaches, simulating field cultivation. These mathematical models also show that the competition that exists in the mixed culture could be the main aspect that affects the yield in relation to the establishment of cereal monocultures. In this study, it was shown that maize was spatially dominant over soybean in intercrops, specifically in the intercropping corn-soybean intercrop, compared to monoculture, and that the reduction in LAI of soybean had negative effects on its growth and grain yield. The transition from the interlayer spatial arrangement to the trip spatial arrangement of the maize-soybean association allowed an increase in the LAI of the soybean and consequently increased the yield of the soybean which was 78.06% for the interleaving arrangement at 43.59% for trip arrangement. In conclusion, the intercropping spatial arrangement of soybeans in association with maize corresponds to an LAI which favors the increase in seed productivity. However, for maize, LAI remains constant under different spatial arrangements with stable grain yield.

Subject Areas

Agricultural Science

1. Introduction

Intercropping has been practiced for long time by smallholder farmers in the tropics. In particular, intercropping of cereals and legumes is recognized as a common cropping system in tropical developing countries [1]. The canopy structure and rooting systems of cereal crops, such as maize or sorghum, are generally different from those of legumes, such as cowpea or soybean. In most cereal-legume intercropping, cereal crops have a higher canopy structure than legume crops, and the roots of cereal crops grow deeper than those of legume crops [2] [3].

This suggests that the component cultures probably have different spatial and temporal use of environmental resources. Intercropping can use environmental resources such as radiation, water, and nutrients more efficiently than monocultures [2]. The productivity of these crops depends mainly on the amount of radiation intercepted by the crops when other factors, such as water, nutrients, diseases and weeds are not limiting [4]. Many studies have shown a positive correlation between crop productions to the amount of radiant energy intercepted by the crop [5].

Among various magnitudes representative of crop status, mention is made of the leaf area index (LAI). LAI is a key variable for studying the functioning of plant surfaces because it determines the exchanges of carbon and water with the atmosphere [6]. It is a relevant indicator of the growth potential [7] [8] [9] [10] or of the nutritional or health status of the crop. LAI is often a central variable in crop simulation models (CERES [11]; SUCROS [12]; STICS [13], where it is generally used to calculate the effective radiation interception for photosynthesis and therefore the production of dry matter.

Many crop models have been developed for the production of the monoculture system [14] [15] [16]. However, few satisfactory cropping models simulate strip and/or intercropping polyculture [17] [18] [19]. Agronomists not only expect these models to simulate and predict agronomic results (yield, dry matter on the vine, water consumption, etc.), but they want these models to be able to help them interpret these results in order to use appropriate cultivation techniques.

To meet these needs, this study aimed to develop a logistical and mathematical approach to simulate the growth of maize and soybeans under intercropping and in strips systems so as to predict the grain productivity of the species taken into account in cereal production in savannah conditions in southwestern DR Congo.

2. Materials and Method

2.1. Plant Material

The vegetative materials used were one variety of quality protein maize (Mudishi-3) and one variety of soybean (Vuangi). The two materials, all obtained by INERA, were chosen for their food preferences and their availability of seeds to users and breeders.

2.2. Method

The experiment was conducted from April to August 2018 at the INERA Mvuazi research center. The trial was carried out during the short growing season from April 10 to August 05, 2018. A factorial design repeated three times was used. An unplugged land was used and later on cleared of any residue covering the soil, The main factor was the type of culture taken at two levels (monoculture and association of cultures), and the second factor was the spatial arrangement taken at two levels in strip and intercrop). The plots were 4 m × 3 m in size for monoculture and the association of corn and soy. Maize was sown at a density of 4 plants per m^2, at a spacing of 1 m × 0.25 m for intercropping and 0.50 m × 0.50 m for strip cropping. On the other hand, soybeans were sown at a density of 36 plants per m^2, at a spacing of 0.40 m × 0.20 m for intercropping and 0.30 m × 0.15 m for strip culture. Figure 1 shows the two types of cultures and spatial arrangements.

2.3. Data Collection

Collected data on maize and soybean included length and width of green leaves, number of visible green leaves (by counting leaves with 50% green area), plant height, collar diameter and grain yield. Data were taken weekly from all the plants in the plots.

The climatic data, rainfall and average daily temperatures that prevailed during the experimental period are presented in Figure 2.

2.4. Simulation Parameters Measurements

The leaf area index (LAI,) is the ratio of the total top surface of the leaves to the surface of the soil on which the vegetation grows. It varies between 2 to 6 for
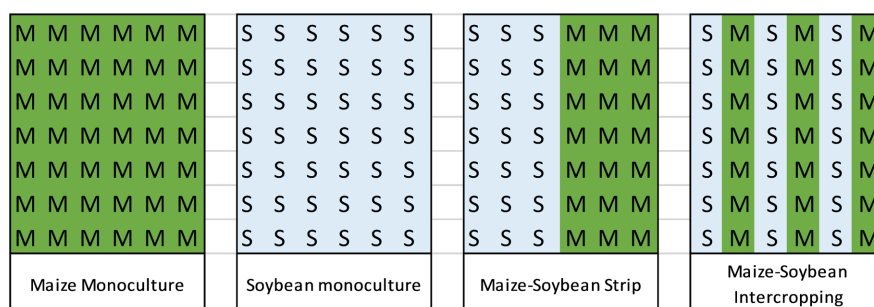

Figure 1. Conceptual diagram allowing the study: M = maize; S = soybean.
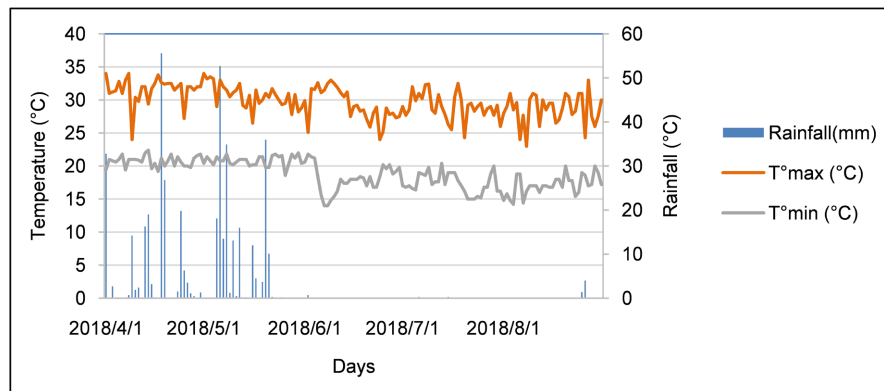
Figure 2. Average daily rainfall and temperatures during the experimental period from April to August 2018.

annual crops [20] and 5.5 for a large seasonal crop such as maize [21] [22]. The LAI was estimated by multiplying the total leaf area (m^2) by the plant density per m^2.

$$LAI = LAt \times d \tag{1}$$

where LAt = total leaf area and d = density per m^2 of area.

The total leaf area of maize and soybeans can be measured manually by the sum total of the leaf area measurement of an individual leaf (LAi).

$$LAt = \sum_{i=1}^{n} LAi \tag{2}$$

Individual leaf area (LAi) is measured using Duncan's Linear Dimension Method [23] [24] [25]:

$$LA = Lv \times wm \times k \tag{3}$$

where Lv = visible length, wm = maximum width and k = 0.75 for the ray leaves and 0.50 for the non-ray leaves of maize, as well as k = 0.50 for each lobe that constitutes the leaves of soybean.

In the absence of water stress, leaf development is a simple function of temperature. The physiological time scale is based on the notion of the sum of degree-days. The thermal time was calculated according to the formula proposed by Bennouna *et al.* [25]:

$$T = \frac{T\max + T\min}{2} - T_b \tag{4}$$

where Tmax and Tmin respectively represent the maximum and minimum daily air temperature, and T_b is the base temperature of the crop, below which there is no growth. Its value for maize is 10°C [25].

2.5. Simulation of Plant Height, Collar Diameter and Leaf Expansion of Maize

The simulation of the plant height and the collar diameter was made according to the logistic equation, on the basis of the estimates of the parameters of the model as defined by Tshiabukole [26]:

$$\text{Plant height} = \text{AsymH}\left[\frac{1}{1+e^{-\text{ScalH}(T_f - T_{iH})}}\right] \tag{5}$$

$$\text{Collar diameter} = \text{AsymD}\left[\frac{1}{1+e^{-\text{ScalD}(T_f - T_{iD})}}\right] \tag{6}$$

With:

AsymH or AsymD: parameter giving the asymptotic response of plant height (H) or collar diameter (D) as time passes to infinity. It has the same units as the answer.

ScalH or ScalD: scale parameter. It is the value of T75% of Asym-T50% of the plant height (H) or the collar diameter (D). This parameter has the same units as variable time.

T_f: parameter giving the time at which all the leaves are senescent (plant growth stops).

T_{iH} or T_{iD}: parameter giving the time of plant height (H) or collar diameter (D) at which the response reaches 50% of Asym. It has the same units as the explanatory variable (time).

The estimates of the model parameters were made on the basis of data collected directly in the field.

The leaf growth dynamics of maize were studied using the semi-mechanistic model of [27] [28], whose equation is as follows:

$$\text{LAI} = \text{LAI}_{\text{Amp}} * \left[\frac{1}{1+e^{-b(T-T_i)}} - e^{-a(T-T_s)}\right] \tag{7}$$

The leaf area index equation is described in two parts, growth and senescence. The growth period is defined using the logistic equation, with parameter *b*, which expresses the growth rate with respect to *Ti*, which is the accumulation of thermal time at the point of inflection. Senescence is determined by means of an exponential equation, with parameter *a*, which expressing the ratio of the growth rate and T_f, the thermal time expressed in cumulative temperatures, where all the leaves are senescent. The LAI_{Amp} parameter describes the maximum amplitude of the LAI. The independent variable *T* represents the accumulation of daily mean air temperature above 10˚C (8˚C for the Baret model) from sowing [27].

The simulation of growth and foliar expansion of maize was made on the basis of data recorded weekly from one week after emergence to maximum height for size and total senescence for LAI.

2.6. Statistical Analyzes of Data

Data collected on the field were subjected to the analysis of variance according to the general linear model (Anova Model < -aov (y~Fact1 + repetition*Fact2 + repetition) and to the multiple comparison test of the least significant difference (LSD) using the "agricolae" package of the statistical software R 3.1.2. Plant height simulation was carried out with the getInitial and SSlogis functions of the R package, procedure for estimating the parameters Asym, Ti and Scal. The function nls (Y~SSlogis (X, Asym, Ti, Scal) of the R package is the procedure for

estimating the parameters and the significance level of the simulation [26]. No-linear regression was performed for the leaf area index "LAI" using the nls function of the R package, which is the procedure for the parameterization (a, b, LAIAmp, Ti, Tf). The calculation of the standard error and the level of significance of the parameters were determined at p = 0.05 (*); 0.01 (**) and 0.001 (***) by the Student test. The different models were evaluated on the basis of observed and theoretically predicted data.

3. Results

3.1. Maize and Soybean Grain Yield

Examination of maize grain yield data showed no significant differences between treatments, arrangements and interactions. The highest yield average was 1980.4 kg/ha for the maize monoculture with intercropping arrangement, and the lowest was 1687.71 kg/ha for the maize-soybean strip intercrop (Table 1 and Table 2).

Regarding soybean seed yield, a significant difference was observed (p < 0.05) between monoculture soybean treatments and soybean in combination with maize. The highest average was 1324.95 kg for the soybean monoculture strip, and the lowest average was 290.67 kg for the soybean-maize strip combination. While for the intercropping associations, the highest average was 879.24 kg for the monoculture of soybeans, and the lowest average was 496 kg for the association of soybeans with maize (Table 3 and Table 4).

Table 1. Estimated model parameters for monocrop and intercrop corn strip and intercrop arrangements for plant height.

Arrangements	Treatments	Model parameters			Grains yield (kg/ha)
		AsymH (cm)	T_{iD} (˚CJ)	ScalH	
Stripcropping	MaizeMonoculure	164.15***	793.80***	198.43***	1697.99
	Maize-soybean	165.02***	863.75***	195.77***	1687.71
Intercropping	MaizeMonoculure	168.19***	946.66***	248.09***	1980.4
	Maize-soybean	164.14***	842.47***	219.31***	1737.71

Sign. code: 0 < α < 0.001 = "***"; 0.001 < α < 0.01 = "**"; 0.01 < α < 0.05 = "*"; 0.05 < α < 0.1 = "†"; 0.1 < α < 1 = "ns".

Table 2. Estimated model parameters for strip and intercrop arrangements of soybeans in monoculture and intercropping for plant height.

Arrangements	Treatments	Model parameters			Grain yield (kg/ha)
		AsymH (cm)	T_{iD} (˚CJ)	ScalH	
Stripcropping	Soybean monoculture	50.32***	722.90***	303.83***	1324.95a
	Soybean-maize	44.96***	674.14***	264.00***	290.67b
Intercropping	Soybean monoculture	49.72***	714.88***	264.78***	879.24a
	Soybean-maize	55.54***	845.76***	346.87***	496.00b

Sign. code: 0 < α < 0.001 = "***"; 0.001 < α < 0.01 = "**"; 0.01 < α < 0.05 = "*"; 0.05 < α < 0.1 = "†"; 0.1 < α < 1 = "ns".

Table 3. Estimated model parameters for monoculture and intercrop maize strip and intercrop arrangements for collar diameter.

Arrangements	Treatments	Model parameter			Grain yield (kg/ha)
		AsymD (mm)	T_{iD} (˚CJ)	ScalD	
Stripcropping	Maize Monoculure	14.10***	197.91***	101.56***	1697.99
	Maize-soybean	13.34***	244.99***	97.18***	1687.71
Intercropping	Maize Monoculure	14.50***	302.11***	89.79***	1980.4
	Maize-soybean	13.00***	278.64***	106.1***	1737.71

Sign. code: $0 < \alpha < 0.001$ = "***"; $0.001 < \alpha < 0.01$ = "**"; $0.01 < \alpha < 0.05$ = "*"; $0.05 < \alpha < 0.1$ = "†"; $0.1 < \alpha < 1$ = "ns".

Table 4. Estimated model parameters for monoculture and intercrop soybean strip and intercrop arrangements for collar diameter.

Arrangements	Treatments	Model parameters			Grain yield (kg/ha)
		AsymD (mm)	T_{iD} (˚CJ)	ScalD	
Stripcropping	Soybean monoculture	4.96***	349.99***	155.58**	1324.95a
	Soybean-maize	4.24***	305.16***	101.91*	290.67b
Intercropping	Soybean monoculture	5.16***	352.71***	149.23***	879.24a
	Soybean-maize	4.38***	270.26***	220.75***	496.00b

Sign. code: $0 < \alpha < 0.001$ = "***"; $0.001 < \alpha < 0.01$ = "**"; $0.01 < \alpha < 0.05$ = "*"; $0.05 < \alpha < 0.1$ = "†"; $0.1 < \alpha < 1$ = "ns".

3.2. Maize and Soybean Growth Simulation

3.2.1. Maize Plant Height

The evolution of plant height in each treatment and arrangement is shown in Figure 3. For all models, the simulations showed highly significant differences ($p < 0.001$) in the monoculture maize and maize with soybean treatments in association (trip and intercropping) for all the estimated parameters (AsymH, TiH, and ScalH).

Table 1 presents the estimates of the maize height simulation parameters. In monoculture, the model estimated the maximum height at 164.15 cm and 168.19 cm respectively for the trip and intercrop arrangement. In the same order, half of the maximum height (TiH) was estimated at 793.80˚CJ and 946.66˚CJ after sowing. In combination, the model estimated the maximum height of maize at 165.02 cm and 164.14 cm respectively for the strip and interlayer arrangement and half the height was estimated at 863.75˚CJ and 842.47˚CJ after sowing (Table 1).

3.2.2. Soybean Plant Height

The growth course of plants in each treatment and arrangement is shown in Figure 4. For all models, the simulations were highly significant ($p < 0.001$) in the monoculture soybean and intercrop soybean-maize treatments (strip and intercrop) for both parameters considered (AsymH, TiH, and ScalH).
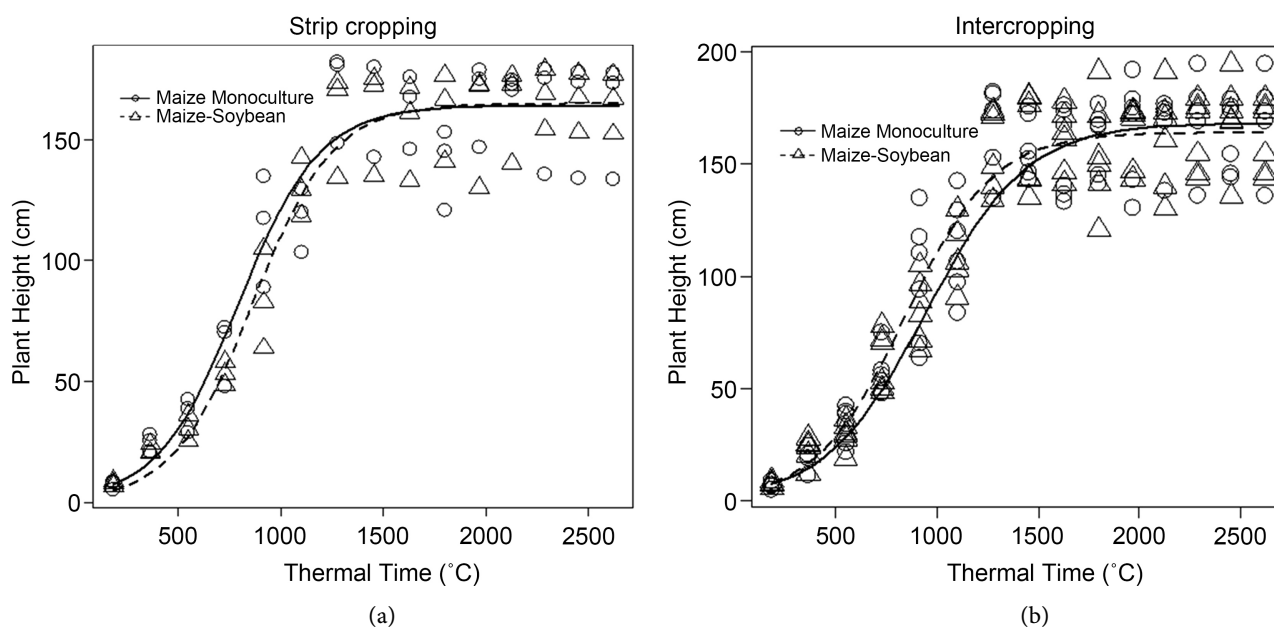
Figure 3. Evolution of the plant height of two maize spatial arrangements (strip cropping and intercropping) in (a) monoculture-reand in (b) association.
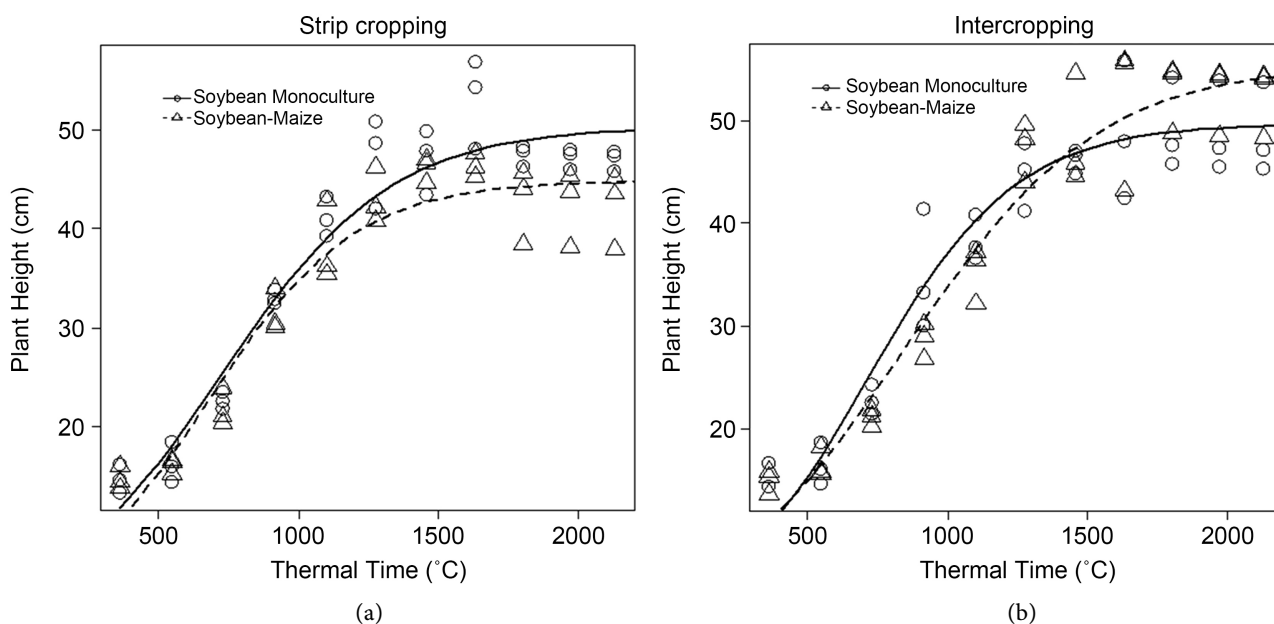
Figure 4. Evolution of the plant height of two soybean spatial arrangements (strip and intercropping) in (a) monoculture and in (b) association.

In the monoculture soybean treatment, the model estimated the maximum plant height to be 50.32 cm and 49.72 cm for strip and intercropping, respectively. Similarly, the half-height was estimated at 722.90°C and 714.88°C after sowing (Table 2).

3.2.3. Maize Collar Diameter
The changes in collar diameter in each treatment and arrangement are shown in

Figure 5. For all models, the simulations were highly significant ($p < 0.001$) in the treatments of maize monoculture and maize with soybean in combination (strip and intercrop) for all parameters (AsymD, TiD, and ScalD).

In the treatment of maize monoculture, the model estimates the maximum collar diameter at 14.10 mm and 14.50 mm respectively for the strip and intercrop arrangement. In the same order, half collar diameter was estimated at the thermal time of 197.91˚C and 89.79˚C after sowing (Table 3).

In the treatment of maize in association, the model estimates the maximum diameter at the collar at 13.34 mm and 13 mm respectively for the arrangement in strip and intercropping. In the same order, half collar diameter is estimated at the thermal time corresponding to 244.99˚CJ and 278.64˚CJ after sowing (Table 3).

3.2.4. Soybean Collar Diameter

The changes in collar diameter in each treatment and arrangement are described in Figure 6. In Table 4, it is noted that the simulations of the variables made with the model were highly significant ($p < 0.001$) in the soybean treatments (monoculture and soybean in association with maize) and in intercropping arrangement for all parameters (AsymD, TiD, and ScalD). On the other hand, for the strip arrangement, the simulations were highly significant ($p < 0.001$) in the treatments of soybean monoculture and soybean in association with maize for the AsymD and TiD parameters. The simulations were also very significant in the treatment of soybeans monoculture ($p < 0.01$) and significant in the treatment of soybeans in association with maize ($p < 0.05$) for the Scal parameter.

Table 4 shows the model parameter estimates for soybean monoculture and intercrop with maize. Estimations were highly significant at $p < 0.001$ and very
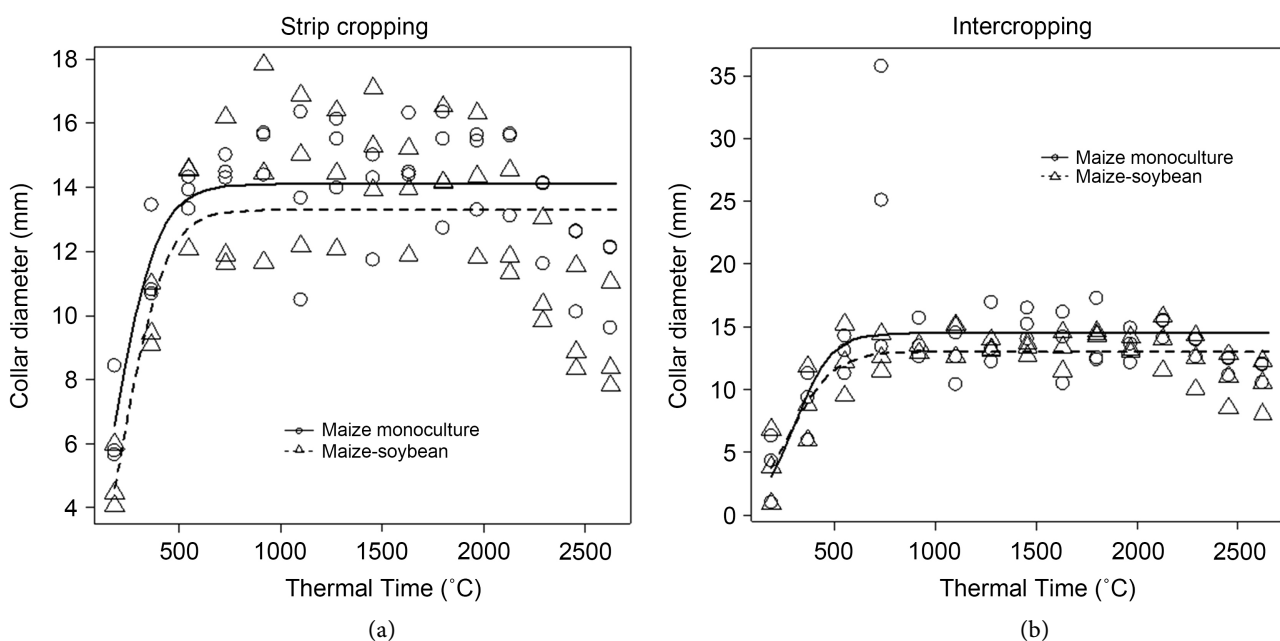

Figure 5. Evolution of the collar diameter of two maize arrangements (strip and intercrop) in (a) monoculture and in (b) association.
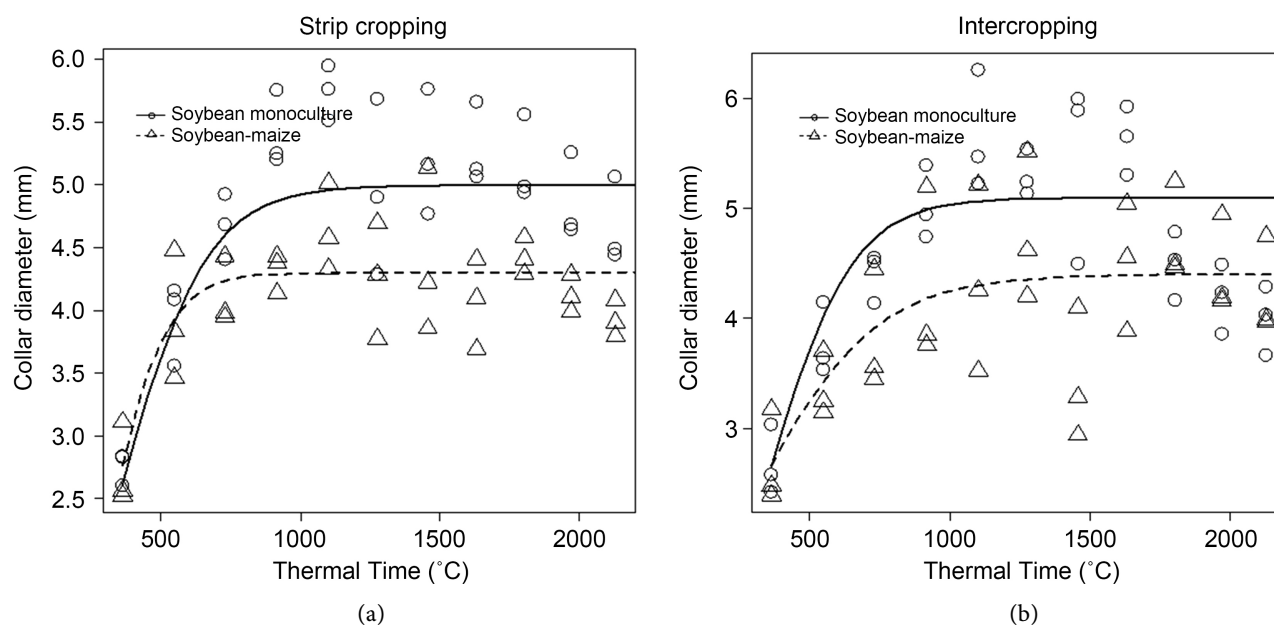
Figure 6. Evolution of the collar diameter of two soybean arrangements (strip and intercrop) in (a) monoculture and in (b) association.

significant at p < 0.01. The model estimated the maximum collar diameter to be 4.96 mm and 5.16 mm respectively for strip and intercrop arrangement for soybean monoculture. Likewise, half collar diameter was estimated at the thermal time of 349.99°C and 352.71°C after sowing. In association with maize, the model estimates the maximum collar diameter at 4.24 mm and 4.38 mm respectively for the strip and intercrop arrangement. Similarly, half the height is estimated at the thermal time of 305.16°CJ and 270.26°CJ after sowing.

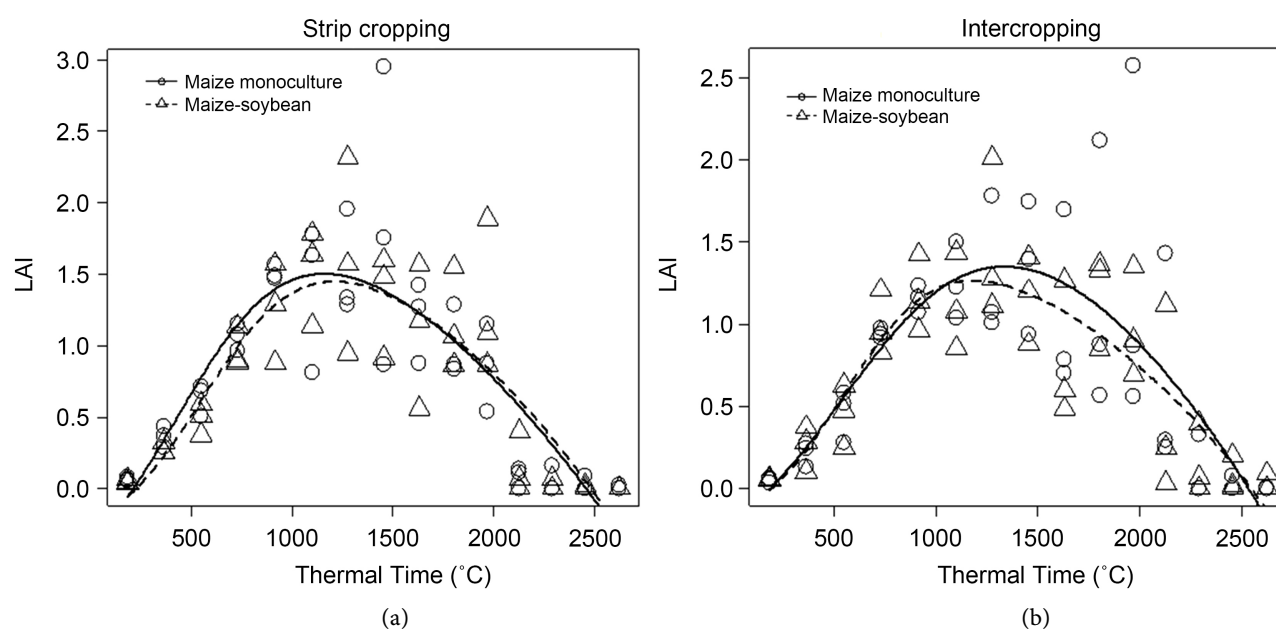### 3.3. Simulation of the Leaf Area Index (LAI)

3.3.1. Maize Leaf Area Index

The estimation of the different parameters based on the STICS model is described in Table 5. The model simulated well the parameters Ti and Tf in the maize-soya association for the two arrangements. Figure 7 shows the evolutions of the observations and the simulation curves of the strip and intercrop leaf indices for the treatments of maize in monoculture and maize in combination with soybean. For all the models, the simulations are significant in the strip maize-soybean treatment (p < 0.05), highly significant in the intercropping (p < 0.001) for the Ti parameter, and also highly significant in all the treatments (maize in monoculture and in association) (p < 0.001) for the Tf parameter.

With regard to Table 5, for the maize monoculture, the maximum leaf area indices (LAIAmpl) were estimated at 3.71 and 3.62 respectively for the strip and intercrop arrangements. Half of these maximum leaf indices were reached at 452°CJ and 591°CJ respectively in strip and intercrop with yields of 1697.99 kg/ha and 1980.4 kg/ha respectively in strip and intercrop. The thermal time required to complete the maize cycle in monoculture was 2459°CJ in strip against

Table 5. Estimated model parameters for the two maize arrangements in the combination and monoculture treatments.

Arrangements	Treatments	Model parameters					Grain yield (kg/ha)
		LAI_{Ampl}	Ti	b	a	Tf	
	STICS	4.27	674	0.0012	0.0074	1657	
Stripcropping	MaizeMonoculure	3.71	452	0.00331	0.000521	2459***	1697.99
	Maize-soybean	2.91	572**	0.003755	0.000684	2482***	1687.71
Intercropping	MaizeMonoculure	3.62	591	0.0026	0.000573	2543***	1980.4
	Maize-soybean	2.21	564***	0.0042	0.00075	2546***	1737.71

Sign. code: $0 < \alpha < 0.001 = $ "***"; $0.001 < \alpha < 0.01 = $ "**"; $0.01 < \alpha < 0.05 = $ "*"; $0.05 < \alpha < 0.1 = $ "†"; $0.1 < \alpha < 1 = $ "ns".

Figure 7. Simulation of the leaf area index of two maize arrangements (strip and intercropping) in (a) monoculture and in (b) association with the thermal weather of seasonal conditions.

2543˚CJ in intercropping. The parameters were also well simulated for the treatment of maize in association with soybeans. The maximum amplitudes of the leaf indices were estimated at 2.90 and 2.21 respectively for the strip and intercrop arrangements. Half of these leaf indices were reached at 572˚CJ in strips and 564˚CJ in intercropping with yields of 1687.71 kg/ha and 1737.021 kg/ha in the same respective order. The thermal time required to complete the maize cycle in monoculture was 2482˚CJ in strip against 2546˚CJ in intercropping (**Figure 7**).

3.3.2. The Leaf Area Index of Soybean

Table 6 presents the estimates of the different parameters based on the STICS model. The model well simulated the thermal parameters Ti and Tf in the soybean-corn treatments for both arrangements. **Figure 8** shows the changes in

field observations and simulation curves of strip and intercrop leaf area index for the treatments of soybean in monoculture and soybean in combination with maize. For all the models used, the simulations are highly significant in the treatments of soybean in monoculture and soybean in association with maize, in strips and in intercropping (p < 0.001) for the parameters Ti, and Tf. In the monoculture soybean treatment, the maximum leaf area index (LAIAmpl) was estimated at 9.17 and 10.14 for the strip and intercrop arrangement, respectively. Half of these maximum leaf indices were reached at 894°CJ and 948°CJ respectively in strip and intercropping with yields of 1324.95 kg/ha and 879.24 kg/ha respectively in strip and intercropping. The thermal time required to complete the cycle of soybeans in monoculture was 2082°CJ in strip against 2095°CJ in intercropping (Figure 7).

Table 6. Estimated model parameters for the two soybean arrangements in the combination and monoculture treatments.

Arrangements	Treatments	Model parameters					Grain yield (kg/ha)
		LAI_{Ampl}	Ti	b	a	Tf	
	STICS	10.58					
Stripcropping	Soybean monoculture	9.17	894***	0.00528	0.00165	2082***	1324.95a
	Soybean-maize	5.78	887***	0.00509	0.00165	2100***	290.67b
Intercropping	Soybean monoculture	10.14	948***	0.00419	0.00151	2095***	879.24a
	Soybean-maize	10.07	1138***	0.00280	0.00139	2138***	496.00b

Sign. code: $0 < \alpha < 0.001 =$ "***"; $0.001 < \alpha < 0.01 =$ "**"; $0.01 < \alpha < 0.05 =$ "*"; $0.05 < \alpha < 0.1 =$ "†"; $0.1 < \alpha < 1 =$ "ns".
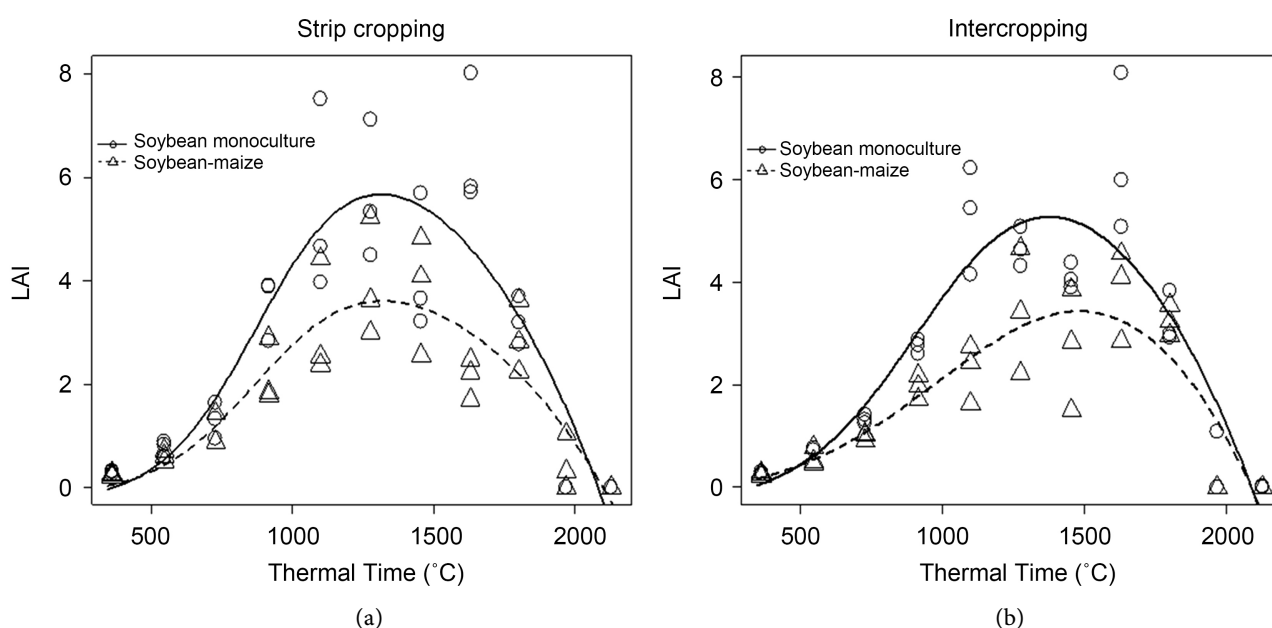

Figure 8. Simulation of the leaf area index of two soybean arrangements (strip and intercrop) in monoculture and in association with the thermal weather of seasonal conditions.

The parameters were also well simulated for the treatment of soybeans in association with maize; the maximum amplitudes of the leaf indices were estimated at 5.78 and 10.07 respectively for the strip and intercrop arrangements with the yields in the same respective order of 290.67 and 496.00 kg/ha. Half of these leaf indices were reached at 887˚CJ and 1138˚CJ respectively in strip and intercrop.

3.4. Discussion

3.4.1. Effect of the Association on Grain Yield

Although the yield of maize did not show a significant difference between treatments, the yield of intercropped maize was higher than that of strip monocropped maize as well as maize intercropped with soybean for both arrangements. On the other hand, different types of the association had an impact on the yield of soybean, which was reduced by 43.59% in strips and by more than 78.06% in intercropping. Although soybean density in the different associations has remained the same (36 plants/m^2), the best combination of row spacing and [soybean] stand density should usually correspond to a leaf area index that intercepts at least 95% of the photosynthesisactive radiation at the start of the seed filling phase [29]. This level of light interception involves the contact of plants located on neighboring rows (maize) so as to fill the intervening space [30]. Similar results were found by Mandal *et al.* [31] for maize-soybean intercropping; as the maize/soybean ratio increased, the more competition reduced soybean yield. This is also the case for other legumes such as cowpea [32] [33] or beans [34] [35].

3.4.2. Simulation of Crop Growth

The greatest maize plant height was recorded in the monoculture treatment with the intercropped spacing and the smallest maize plant height was recorded in the maize-soybean intercrop with the intercropped spacing. The mean value obtained for maize plant height slightly approaches that obtained by Tshiabukole *et al.* [10] when simulating the growth of quality proteins in maize under optimal crop conditions. On the other hand, the collar diameter did not undergo significant differences between all the treatments, demonstrating that the maize had maintained its vigor despite the variations of treatments.

According to Salez [36], the maize height is never affected by the association with a legume after he recorded on all his tests carried out a difference of 0 to 6% (average = 2%) of height and that the difference was not significant between maize treatments in monoculture and in association with grain legumes. Barkers *et al.* [37] reported that maize competition strongly reduced LAImax and legume height but that legumes only reduced maize height by up to 2%. And as a cover crop, soybean had a greater height in the intercropping maize strip treatment and the lowest soybean plant height was recorded in the intercropping maize strip intercropping treatment as the spatial arrangement. However, soybean collar diameter was influenced by intercropping with strip and intercrop maize,

showing low soybean plant vigor. These results can be explained by the fact that light is one of the crucial factors affecting competition in the mixed canopy. Interception and attenuation of light in the canopy are important in assessing potential carbon uptake by crop and are determined by canopy structure [38].

Plant height and collar diameter are among the informative variables that play a key role in assessing competition for light in cover crops [39]. Hang *et al.* [40] or Even [41] have also demonstrated that plant height was increased in competition for light while biomass per plant was reduced. Conversely, some species may be at lower levels of competition in association than in pure culture [42].

3.4.3. Simulation of the Leaf Area Index

The production of a crop depends on the interception of solar radiation and its conversion into biomass. The amount of incident radiation that is intercepted by the plant is determined by leaf area, leaf orientation and leaf life. The maize leaf area index has a positive effect on radiation interception up to a value of about 4; beyond that, the additional surface has little effect on the light interception. Planting density is a determining factor of LAI [43].

Plants exposed to the greater competition show a series of changes characteristic of shade avoidance syndrome. The shading phenomena would be reflected at the level of the photosynthetic organs by thinner leaves, a reduction in the specific weight of the leaves and an increase in the leaf area index [44].

In view of the results obtained in this study, it appears that the associations of crops, whatever the spatial arrangements, had a negative effect on legumes with regard to leaf expansion. This confirms the conclusions of Willey [2] and Tsubo *et al.* [3], which stipulated that in most cereal-legume intercrops, the cereals take advantage of the legumes because of the higher canopy structure than the cereal legumes crops, and the roots of cereal crops grow deeper than those of legume crops.

According to Loomis and Williams [45], grain yield is dependent on crop radiation interception when other factors, such as water, nutrients, disease and weeds are not limiting. Any internal modification characterized by any position of the culture to face the radiation would influence the productivity of the culture. The results obtained in this study verify the hypotheses developed by Loomis and Williams [4], which can be supported by the positive correlations obtained by Monteith [45] and Tsuboat al. [5] for agricultural production and the amount of radiant energy intercepted by the crop.

4. Conclusion

It appears from this study that the LAI between species is a crucial element in the functioning of associations due to the involvement of this resource in multiple processes. The results obtained showed that there was great competition for space management in the associations (more precisely in the spatial arrangement in the strip) compared to the monocultures on the cover plant (soybean). This

implies that the LAI of the dominant species, maize in our case, had a direct impact on the dominated species, which is soybean. The reduction in the soybean leaf area index may have had negative effects on its growth and grain yield because competition for growing space may also have affected the symbiotic physiology of the legume.

Acknowledgments

Conflicts of Interest

The authors declare no conflicts of interest.

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