Maize-coconut intercropping: effects of shade and root competition on maize growth and yield

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Maize–coconut intercropping: effects of shade and root competition on maize growth and yield

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Abstract – Maize was grown simultaneously under artificial and under natural shade from coconut palms. Under artificial shade, the more solar radiation was intercepted, the less the maize developed and yielded. Under our experimental conditions, where photosynthetically active radiation (PAR) was the only limiting factor, there was a simple linear relation between yield and PAR. Applying this relation to a maize–coconut intercropping system gave an estimated yield slightly higher than the actual harvest. This may be due to the difference between radiation interception by shading canvas and that obtained with a coconut cover. A second explanation may be root competition between the two crops. Although this competition indeed exists, it was not detected in our experiment due to the excellent soil and climatic conditions. Our experiment also showed that in maize, net assimilation response to PAR did not depend on the received light treatment. (© Inra/Elsevier, Paris.)

maize / coconut / photosynthesis / radiation / competition / shade

Résumé – Association maïs–cocotier : effet de l'ombrage et de la compétition racinaire sur la croissance et le rendement du maïs. Du maïs a été cultivé parallèlement sous ombrage artificiel et sous ombrage naturel de cocotier. Sous ombrage artificiel, plus le rayonnement solaire est intercepté, moins le maïs se développe et produit. Dans nos conditions expérimentales, où le seul facteur limitant était le rayonnement PAR, une relation simple et linéaire entre production et éclairement PAR a été obtenue. L'application de cette relation à une association cocotier/maïs donne une production estimée légèrement supérieure à celle récoltée. Ceci peut s'expliquer par la différence d'interception du rayonnement entre un filet d'ombrage et un couvert de cocotier. Une seconde explication provient de la compétition racinaire entre les deux cultures. Celle-ci, bien qu'existant réellement, n'a cependant pas pu être mise en évidence au cours de notre expérimentation du fait de conditions pédo-climatiques excellentes. L'expérience a en outre montré que chez le maïs, la réponse de l'assimilation nette à l'éclairement PAR ne dépend pas du traitement lumineux reçu. (© Inra/Elsevier, Paris.)

maïs / cocotier / photosynthèse / rayonnement / compétition / ombrage

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1. INTRODUCTION

Around 11.5 million hectares world-wide are currently planted with coconut (*Cocos nucifera* L.). According to Persley [28], 96 % of world copra comes from smallholdings of less than 4 ha, in which coconut is almost always combined with other crops. In fact, either from habit or due to increasing land pressure, smallholders combine coconut with other crops to make maximum use of the areas planted by intensifying their cropping system. There is ample literature on coconut-based cropping systems, and coconut is intercropped with various plants [23], such as medicinal and aromatic plants [30], groundnut [17], cocoa [6, 11], coffee [24], pepper, clove and ginger [23], pineapple and banana [3, 23], passion fruit [2] and soybean [14, 21]. The intercrops grown with coconut are necessarily food crops. For instance, creeping legumes (*Pueraria javanica*, *Centrosema pubescens*, *Calopogonium mucunoides*, etc.) are often recommended with coconut to maintain soil nitrogen fertility [5], or tree legumes such as *Leucaena leucocephala* or *Acacia mangium*, which also supply firewood [19, 29, 31]. Vanuatu is also worth mentioning as a specific case: its smallholders combine immature coconut palms with food crops (cassava, taro, yam, groundnut), and subsequently with livestock rearing.

Most of this work studied the economic aspect of the intercrop combination, emphasizing the improvement in grower income [1, 27]. There were few results concerning inter- and intraspecific competition. In the case of root competition, the authors often considerably simplified the root system architecture of each plant [18, 25] and considered root competition to be non-existent. However, in an intercropping system of coconut palms (aged 5 years) and cocoa trees (aged 2 years), Colas [7] showed that root system competition did exist between the two plants and that, at that period, intraspecific competition also occurred between the coconut palms.

As regards aerial competition, coconut is generally the dominant plant apart from the earlier years after planting. Nair [25] measured changes in the photosynthetically active radiation (PAR) solar energy reaching the ground in a coconut stand depending on the age of the palms. Dauzat [9, 10] modelled the architecture of the coconut palm and generated virtual coconut stands in which he carried out simulations of light transmission. He was then able to calculate the percentage of light transmission through the coconut canopy depending on the geographical location of the site, the age of the coconut palms and the adopted planting design, and to recommend the most suitable plants according to the light environment under coconut.

The study of maize–coconut intercropping described here covered competition for light, since the amount of radiation transmitted through the coconut canopy is almost certainly the main limiting factor for intercrop growth. Our aim was to study the effect of the light received on maize growth, development and yields, and on its photosynthesis capacity. A relation between the light received and yields was sought, so as to integrate it into a coconut-based farming system operational model. The experiment was also aimed at an initial assessment of the constraints that coconut may exert on a maize intercrop, due to root competition.

2. MATERIALS AND METHODS

A trial combining coconut and maize was conducted in a plot at the Vanuatu Agricultural Research and Training Centre on Santo Island. On these slightly desaturated, humus-rich, clay ferrallitic plateau soils of coral origin, immature hybrid coconut palms (Vanuatu Red Dwarf x Vanuatu Tall) were intercropped with various food crops [26].

The coconut palms were planted in 9-m triangles, i.e., a planting density of 143 palms per hectare.

The maize – a local white variety – was planted 25 cm within the row, with 75 cm between rows. Under coconut, an experimental plot in an inter-row was 27 m long by 5.25 m wide, and comprised seven rows of maize.

Simultaneously, so as to study the effects of radiation on maize growth and development in a monoculture, plots were set up under artificial shading. Four radiation treatments were studied: full sunlight (open) and light interception rates of 30, 50 and 70 %, obtained with different shading canvases. The canvases were installed at a height of 2.20 m, and the plots in this case were 11 m long by 5.25 m wide, also comprising seven rows of maize. Given the shade cast, which caused significant border effects, the 'control' plots were grouped together. As a result, the planting design was not statistical. However, given the richness of the soil, we feel that the area must have been highly uniform and that there was little chance of it having a significant effect on the maize. We therefore decided to attribute the difference detected by an analysis of variance to the effect of the treatments alone.

The PAR transmission rate of each shading canvas was verified using sensors with amorphous silicon photoelectric cells [12]. Four sensors per plot, plus a reference sensor in the open, were connected to a Campbell CR10 data logger. The values were measured every 5 s and the means calculated every 5 min. The true transmission rates are shown in *table I*. Each value represents the mean of several days' measurements. With the exception of the 50 % treatment, the experimental values were very close to those claimed by the canvas manufacturer.

At the same time, PAR transmission through the coconut canopy was also measured. The experimental design was similar to that used by Dauzat [8], with 32 sensors laid out in two adjacent triangles on the ground, plus one to record incident radiation above the canopy. The measurements made over 4 sunny days showed that the mean transmission rate was 29 %.

Given the availability of the different types of shading canvas, the numbers of replicates per treatment were as follows: 100 % (= full sunlight): nine plots; 72 % transmission: four plots; 41 % transmission: two plots; and 31 % transmission: three plots.

Under coconut, the design already set up for a study of coconut–food crop intercropping was used for our study. Besides the 12 plots available, we planted another two, around which a 1-m deep trench was dug and then filled in before planting maize. This design was intended to substantially reduce root competition between the two plants. Moreover, a comparison of the results of the 'intercropping' and 'intercropping + trench' treatments was supposed to enable us to assess the constraints on maize as a result of root competition with coconut. The monoculture plots were around 100 m from those with intercrops.

Table I. Light transmission rates measured.

Treatment	Manufacturer's transmission %	Measured transmission %
30 % canvas	70	72
50 % canvas	50	41
70 % canvas	30	31
8-year-old coconut palms		29

In all the treatments, a certain number of phenological observations was carried out during the growth cycle. The studied parameters, and the number of maize plants included in the study, are shown in *table II.*

Concerning physiology, the curves for net photosynthesis saturation by radiation were obtained for the four light treatments to observe the effect of the light treatment on maize photosynthetic response. The measurements were made with an ADC LCA4 IRGA (infrared gas analyzer).

Lastly, a leaf analysis was carried out on maize, as described by Loué [20], to check mineral nutrition.

3. RESULTS AND DISCUSSION

3.1. Leaf nutrient contents

The results of the leaf analysis performed around 64 days after emergence are given in *table III.* According to the contents range defined by Jones [15, 16], maize nutrition was good. With the exception of K contents in the 'intercropping' and '31 % transmission' treatments, which were excessive, and the Mg content in 'intercropping', which was low, the other contents were satisfactory or high. As no cases of deficiency were recorded, mineral nutrition was not a limiting factor for maize under the conditions of our experiment.

It is important, however, to note that there was a decreasing gradient of contents, from the 31 % treatment to the 100 % transmission treatment. With the exception of calcium, the gradient was systematic, and can be attributed to nutrient dilution. In fact, the higher the transmission rate, the greater the vegetative development of the plants, and the more the nutrients were diluted in the tissues. The search for correlations between leaf contents and the dry weight of the aerial parts revealed negative relations for which the correlation coefficients were high (*figure 1*).

Table II. Studied parameters and number of observed plants.

Studied parameters	Number of observed plants
Plant height – 24 days after planting – 44 days after planting – 58 days after planting – 73 days after planting Collar diameter No. of leaves per plant	Observations carried out on 91 individuals per plot (13 plants per row)
Area of leaf under the highest cob	Ten individuals per plot
Cob dry and fresh weights No. of cobs	All individuals (results per plot and per row)
Individual cob weight (total, grains and empty cob)	At least 50 individuals per plot
Aerial dry and fresh organ weights	All plants and per row
Weight of 100 grains	12 measurements on a composite sample per treatment
No. of primary roots	30 individuals per plot
Primary root diameter	Eight measurements on each of the above 30 individuals

Table III. Mean nutrient leaf contents and aerial dry weights for maize.

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Aerial dry weights (g·plant^{-1})
Intercropping	3.218 (c)	0.362 (c)	2.527 (ex)	0.439 (c)	0.181 (f)	45
Intercropping + trench	3.622 (e)	0.361 (c)	2.381 (e)	0.511 (c)	0.206 (c)	37
100 % transmission	2.955 (c)	0.288 (c)	1.994 (c)	0.537 (e)	0.214 (c)	81
72 % transmission	3.211 (c)	0.312 (c)	2.150 (c)	0.535 (e)	0.235 (c)	67
41 % transmission	3.371 (c)	0.323 (c)	2.326 (e)	0.456 (c)	0.264 (c)	44
31 % transmission	3.496 (c)	0.345 (c)	2.512 (ex)	0.495 (c)	0.256 (c)	33

Contents defined as per Jones [15]: d = deficient; f = low; c = satisfactory; e = high; ex = excessive.

3.2. Effects of light treatment on different growth parameters

Plant height was monitored regularly during the growth cycle. In general, the more light received, the faster the maize grew (*figure 2*) and the greater its height at the time of flowering. On flowering, apart from the '72 % transmission' treatment, which was not significantly different from the control, the other treatments individually belonged to statistically distinct groups (*table IV*), of which the mean fell in line with the transmission rate.

Measurements of collar diameter and the number of primary roots in the four treatments produced a similar classification (*table V*). Light interception had a depressive effect on collar diameter and root number: the mean diameter fell from 2.0 cm in the open to 1.1 cm when 31 % of the radiation was transmitted, whilst the number of primary roots fell from 35.8 to 29.5. However, there was no significant effect on primary root diameter, which did not seem to depend on the treatment.

A study of leaf areas confirmed these results. In fact, the number of leaves and the area of the leaf

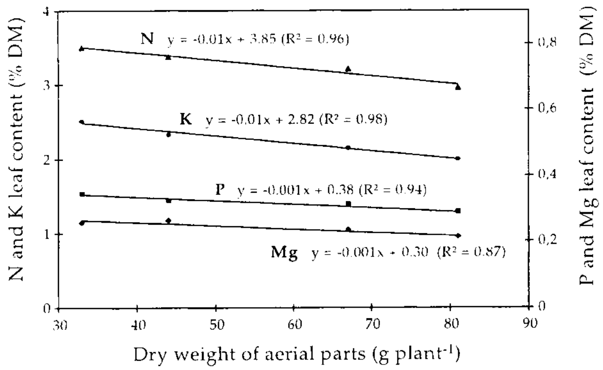

Figure 1. Correlation between leaf nutrient contents and dry weight of aerial parts of maize.

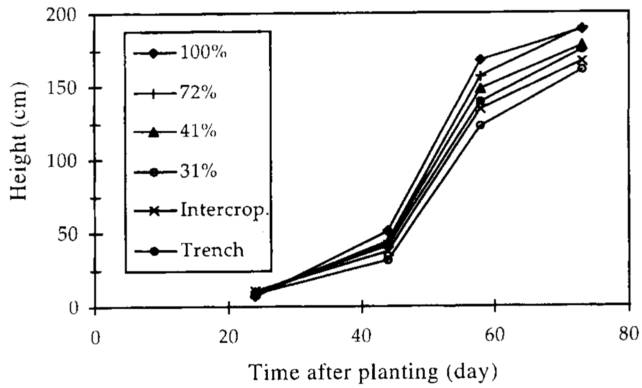

Figure 2. Increase in plant height according to time and treatments.

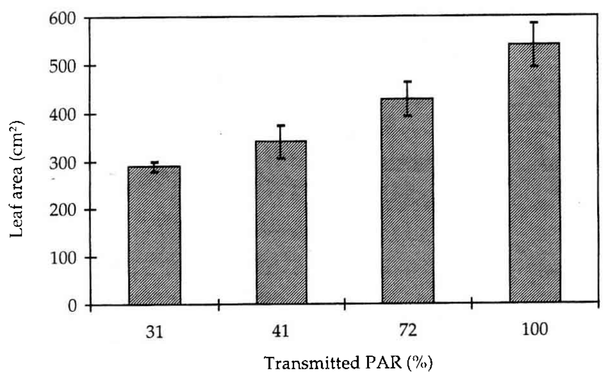

Figure 3. Area of the leaf under the highest cob depending on the treatment. Vertical lines represent standard error of the mean. PAR: photosynthetically active radiation.

Table IV. Plant height to base of spikelet (73 days after planting).

Transmission (%)	Height to base of spikelet (cm)	Statistical group
100	188.2 ± 27.3*	a
72	189.4 ± 30.2	a
41	171.0 ± 25.9	b
31	160.6 ± 24.7	c

The groups with different letters are statistically different; *: standard error of the mean.

Table V. Collar diameter and number and diameter of primary roots.

Transmission %	Collar θ (cm)	No. of primary roots	Primary root θ (mm)
100	2.0 ± 0.2 a	35.8 ± 5.6 a	3.2 ± 0.5 a
72	1.7 ± 0.5 b	33.8 ± 6.9 ab	3.2 ± 0.7 a
41	1.3 ± 0.5 c	31.8 ± 5.6 abc	3.0 ± 0.6 a
31	1.1 ± 0.3 d	29.5 ± 5.4 c	2.9 ± 0.5 a

Each letter corresponds to a different statistical group.

under the highest cob were greater the higher the rate of radiation transmitted (*table VI* and *figure 3*). The differences were particularly marked in the case of the area of the leaf under the highest cob, for which each treatment was significantly different from the others.

For yield, the study covered not only the quantity of cobs and grains and some of their characteristics, but also the weight of the aerial parts harvested at the end of the trial. To simplify matters, certain results are given in tonnes per hectare, for a planting density of 50 000 plants/hectare.

The total yield (vegetative part + cobs) of the 'open' control was around 22 $t \cdot ha^{-1}$ of fresh matter, including just under 9 t of cobs (*table VII*). The effect of shading was marked, and confirmed the previous observations of growth parameters. Light radiation interception reduced not only vegetative part production, but also fruiting. In fact, fresh matter production (vegetative part) decreased from 13.8

Table VI. Number of emitted leaves on each treatment.

Transmission %	No. of leaves
100	11.1 ± 1.2 a
72	10.6 ± 1.4 b
41	10.6 ± 1.3 b
31	10.1 ± 1.2 c

Each letter corresponds to a different statistical group.

Table VII. Yield parameters.

Transmission %	Fresh matter weight, aerial parts ($t \cdot ha^{-1}$)	Cob weight ($t \cdot ha^{-1}$)	Weight of 100 grains (g)
100	13.8 ± 2.6 a	8.6 ± 1.7 a	21.5 ± 0.5 b
72	11.1 ± 2.9 a	6.3 ± 1.8 a	22.8 ± 0.5 a
41	8.4 ± 2.6 b	4.1 ± 1.3 b	17.9 ± 0.6 c
31	6.2 ± 2.3 c	2.6 ± 0.7 c	15.5 ± 0.5 d

Each letter corresponds to a different statistical group.

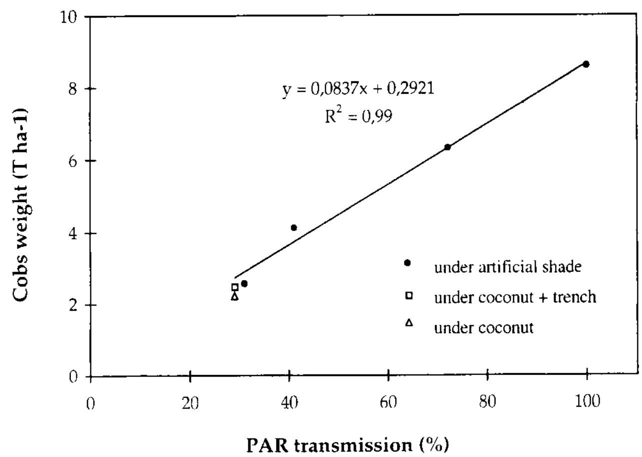

Figure 4. Relation between yield in tonnes of cobs per hectare and photosynthetically active radiation (PAR).

$t \cdot ha^{-1}$ in the open to 6.2 $t \cdot ha^{-1}$ with the densest shade (intercepting 69 % of light radiation), whilst cob yields per hectare fell from 8.6 to 2.6 $t \cdot ha^{-1}$.

These data were used to determine the relation between yield and radiation transmission rate (*figure 4*). It was seen that for yield expressed in tonnes of cobs per hectare (y) and radiation transmission rate in % (x), the relation was simple and linear. The equation for the correlation line was as follows:

$$y = 0.0837x + 0.2921 \ (R^2 = 0.99) \ (1)$$

This equation could be used to forecast maize yield potential, when light radiation is the only limiting factor for maize.

3.3. Case of plots under coconut

The transmission rate measured in our experimental coconut plot was 29 %. According to equation (1), the expected maize yield under identical artificial shade would be 2.7 $t \cdot ha^{-1}$. However, we obtained 2.2 $t \cdot ha^{-1}$ on average. This difference can be attributed to:

1) the fact that the radiation transmitted through a coconut canopy is very different, in terms of both quality and quantity, from that transmitted through artificial shading. In fact, the latter is uniform, whereas natural shading under coconut is highly heterogeneous, hence radiation distribution varies in both time and space. Moreover, spectral quality is also modified, with a variation in the zeta ratio (light red:dark red ratio). The fact that the maize did not receive the same radiation in both cases may explain the differences in growth and development.

2) the presence of coconut palms, which may have had a depressive effect on the intercrop given that the root systems of the two crops were in competition. This competition for water and nutrients may have resulted in reduced maize growth and development.

Nevertheless, the latter explanation seems unlikely under our experimental conditions. In fact, around certain plots of maize intercropped with coconut, a 1-m deep trench was dug and then filled in before planting the maize. This substantially reduced root competition between coconut and maize, and the maize could have been expected to perform better in these plots than in simple intercrop plots.

However, a comparison of the 'simple intercropping' and 'intercropping + trench' treatments (*table VIII*) revealed only a slight difference. In fact, except for the number of primary roots and their mean diameter, there was a difference in favour of the treatment with trenches, but a statistical analysis showed that it was only significant in the case of the number of leaves and the weight of 100 grains. Moreover, there was no significant effect on yields.

The depressive effect of coconut on maize, due to competition (for water and nutrients) between their respective root systems, was thus only slight. This can be put down to two factors:

1) Rainfall was amply sufficient to cover the water requirements of both crops. As a result, even though the root systems were in competition, the abundant rainfall meant that this had no tangible effect.

2) The soils on which the trials were performed were rich. The fact that there were sufficient nutrients in the soil thus ensured the satisfactory mineral nutrition of both crops.

The good soil and climatic conditions therefore prevented the detection of any significant depressive effects on maize that may have resulted from competition between the root systems of the two crops. However, competition existed, as digging trenches immediately after harvesting revealed that in places, the root systems were interwoven, used the same soil volumes and were thus at least potentially in direct competition.

With regard to the physiology, we wanted to see whether the light treatment influenced the photosynthetic potential of maize. To this end, we studied the equation giving net assimilation in relation to light for each type of shading. In the open (100 % transmission), the curve for photosynthesis saturation by light was conventional (*figure 5D*), and the best negative exponential adjustment was as follows:

$$A = 39.55 \times (1 - \exp(-0.06 \times (PAR - 55.82) / 39.55)) \quad (R^2 = 0.96) \quad (2)$$

where A is net assimilation and PAR the photosynthetically active radiation received by the plant at the time of measurement.

The experimental points were closely grouped and maximum net photosynthesis was around 40 μmol CO_2 m^{-2} s^{-1}. This value was high compared to those obtained on tree crops, and is due to the fact that maize belongs to the C4 group of plants (unlike coconut, for instance, which is in C3). However, it tallies with the values measured on selected maize varieties [13].

Table VIII. Comparison of parameters in plots intercropped with coconut, with and without trenches.

Parameters	Simple intercropping with coconut	Intercropping + trench
Height 73 days after planting (cm)	166.5 ± 24.6 a	174.4 ± 23.1 a
Collar diameter (cm)	1.2 ± 0.5 a	1.3 ± 0.2 a
No. of primary roots per plant	31.7 ± 5.8 a	29.5 ± 5.1 a
Mean primary root diameter (mm)	3.0 ± 0.8 a	2.8 ± 0.5 a
Mean no. of leaves	9.7 ± 1.2 a	10.6 ± 1.1 b
Mean area of leaves under the highest cob (cm^2)	398.3 ± 37.6 a	426.7 ± 11.1 a
Fresh matter weight of vegetative parts ($t \cdot ha^{-1}$)	6.2 ± 1.1 a	7.0 ± 1.0 a
Cob weight ($t \cdot ha^{-1}$)	2.2 ± 0.5 a	2.5 ± 0.5 a
Weight of 100 grains (g)	15.2 ± 0.5 a	16.7 ± 0.6 b
Yield (t cobs ha^{-1})	2.20 ± 0.5 a	2.45 ± 0.5 a

Each letter corresponds to a different statistical group.

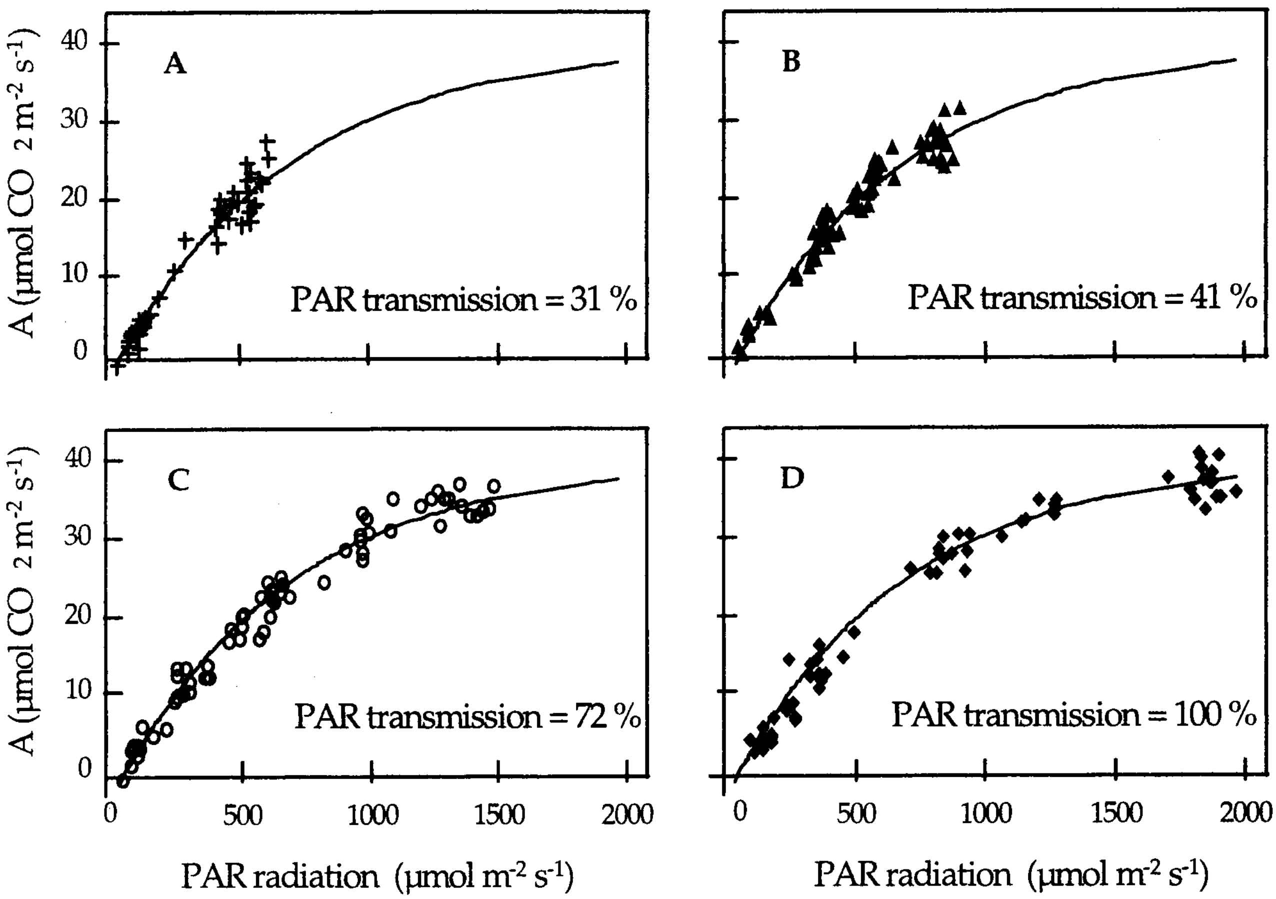

Figure 5. Relation between net photosynthesis and photosynthetically active radiation (PAR) depending on the treatment: A = 31 %, B = 41 %, C = 72 % and D = 100 % PAR transmission.

In the case of the other three shading treatments (*figure 5A–C*), the assimilation values depending on radiation were not very scattered compared with the curve obtained in the open. Plotting the points on the same graph (*figure 6*) showed that the above adjustment was still valid (R^2 = 0.96). Unlike many plants, which adapt to radioactive conditions [4, 22], maize seems to respond in the same way irrespective of the amount of radiation received during growth. The result is that provided that water and nutrient supplies are not limiting, knowing the percentage of radiation received makes it possible to forecast the amount of carbohydrate produced by maize.

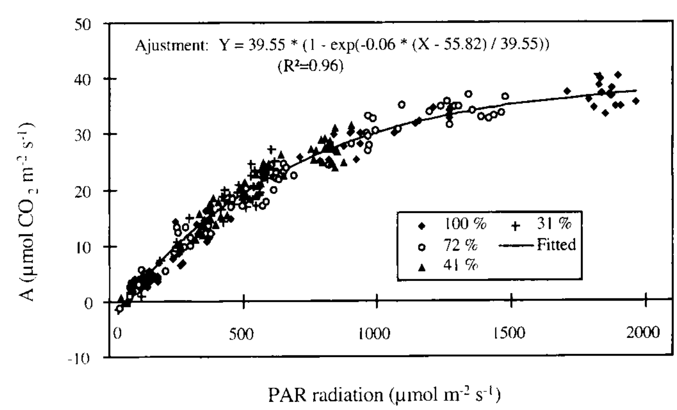

Figure 6. Relation between net photosynthesis and photosynthetically active radiation (PAR), with all treatments combined.

4. CONCLUSION

This trial demonstrated the effect of radiation on maize yield, growth and development. Reducing the radiation received by artificial shading had a depressive effect on all the studied parameters, which was all the more intense the greater the interception rate. Using artificial shading of increasing light intensity produced a relation between yield and the interception rate of the canvas. The relation is linear and can be expressed as in equation (1). Moreover, a study of gas exchanges in the plants in the different treatments showed that the amount of light received by the maize did not modify its photosynthetic response to light. In fact, the respond curve to light did not seem to vary depending on shading. Given the light received by the maize, equation (1) can be used to forecast potential yields, provided radiation is the only limiting factor.

Applying equation (1) to a maize–coconut intercropping system in Vanuatu gave estimated yields 20 % higher than those obtained in the field.

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