CAFOBIOS
Cameroon Forum for Biological Sciences

Available online at http://cajeb.ifrance.com

Cameroon Journal of Experimental Biology 2008 Vol. 04 N° 01, 29-38

Original article *Agronomy*

Ecophysiological responses of peanut (*Arachis hypogea*) to shading due to maize (*zea mays*) in intercropping systems

Sêdami Baï ADJAHOSSOU[1], Firmin Dossou ADJAHOSSOU[2], Brice SINSIN[2], Michel BOKO[3], Jorge VIEIRA da SILVA[4]

[1]Ecole Polytechnique d'Abomey-Calavi (EPAC/UAC); 01BP 2417 Cotonou, Bénin
[2]Faculté des Sciences Agronomiques-Université d'Abomey-Calavi (FSA/UAC), 01BP 526 Cotonou, Bénin
[3]Faculté des Lettres Arts et Sciences Humaines-Université d'Abomey-Calavi (FLASH/UAC) ; BP 55 Abomey-Calavi
[4]Université Denis Diderot/Paris, France ; Les Bélliards 41320 Maray France
Corresponding author: ADJAHOSSOU Baï Sêdami, 01 BP 2417 Cotonou, Bénin, Tel.: +229 21 38 41 63; E-mail : sedajas@yahoo.fr

ABSTRACT
The purpose of this study is to evaluate, in an experimental station, the quantitative impact of shading on the productivity of peanuts, by intercropping with three varieties of maize. Sufficient water and fertilizers were provided and several levels of shading were induced. During the 2003 growing season, shading was induced with three sowing densities of maize DMR-ESRW, a planophile variety of maize. During the 2004 growing season, three intercropping varieties, TZEEW, DMR-ESRW and Obatanpa, were evaluated for shading of the peanut canopy. The main data collected were etiolation, dry matter productivity and seeds yield. 'Gynophore index', which integrates both growth and seed yield aspects, was also measured. Results showed significant differences for measured parameters, in correlation with light reduction. According to the density and the variety of the maize intercropped, residual light above the peanut canopy, varied from 72 % to 53 %. The length of main axis varied from 51.4 cm for control plot of peanut alone to 63.9 cm for peanut intercropped, with maize variety DMR-ESRW. Etiolation contributes to reduce the number of pods. The impact of this reduction was estimated with gynophore index; highly correlated with number of pods. Dry matter and seed yield dropped respectively by 35 % under TZEEW and 55% under DMR-ESRW. The relationship between the yield reduction and the extent of shading reflected the steps of adaptation of groundnut to the lack of light stress.

Key words: Peanut, Maize, Intercropping, Etiolation, Gynophore index.

INTRODUCTION

In the "Département de l'Atlantique" (Republic of Benin), land available for cultivation is gradually decreasing, because of the rapid expansion of the main city, Cotonou. Thus, limited cultivable land is facing pressure to satisfy larger demands for food. Moreover, smallholders are providing most of the food needed via traditional systems of production, characterized by low productivity. Formerly, the traditional system was more efficient and stable as the fallow period was adequate. Currently, the fallow period is shortened in the area, and consequently, the land is subjected to continuous degradation, with more weed infestation and reduction of crop production [1]. Due to their high cost and scarcity, the use of chemical fertilizers is not a viable option for most smallholders. Moreover, these soils require organic matter supply in addition to chemical nutrients.

In the low-input agrosystems, intercropping is a sustainable practice that can increase the use of solar radiation and improve crop production. In the intercropping systems, the efficiency of the partner crops combination depends on several factors such as the population habit, life span and management practices of the crops. Nevertheless, the major factor is the crop geometry [2]. In most cases, dominant and subordinate partners constitute the intercrop mixture and the combination may allow a sufficient quantity of radiation to reach the subordinate crop [3, 4]. The dominant crop usually has an erectophilous architecture and absorbs incident radiation very effectively through the leaves' surfaces, while the subordinated crop is selected from planophile canopies which trap the maximum quantity of radiation transmitted from the dominant crop [4, 5]. Over the past two decades, several studies dealing with intercropping systems, alley cropping systems and agroforestry, were reported and implicated wide range of crop combinations [6, 7, 8, 9].

Very few studies have examined the association of maize and peanuts [10, 4]. Nevertheless, in the *"*département de l'Atlantique*",* maize and peanut provide a substantial part of the basic food needed and the association of these two partners' crops is common. Competition for water, nutrients and light occur in intercropping systems. Despite this competition, intercropping systems appear to be productive, stable and sustainable [7]. However, the level of yield is below the basic need of the population. Therefore intercropping systems must be intensified, with adequate water and nutrients supply. Under such non-stressed environmental conditions, the availability of solar radiation and its partitioning become the major limiting factors for productive efficiency [11].

The objective of this study is to evaluate the impact of three levels of shading on some physiological parameters and the productivity of peanuts, when used as the subordinated partner in combination with three different varieties of maize under adequate environmental conditions, such as fertile soil and ample water availability.

Materials and methods

Field experiments

The field experiments were conducted at Zinvié-Kpotomey, municipality of Abomey-Calavi (latitude 6° 37' N longitude 2° 23' E), during two growing seasons in 2003 and 2004. A local peanut variety belonging to the 'Spanish' group was sown at a density of 11.1 plants per m^2. During the 2003 growing season, treated plots were intercropped with local maize, with three levels of imposed shading, determined by three levels of maize plant densities (4.2, 3.1 and 2.5 plants/m^2).

For the 2004 growing season, shading was imposed by intercropping peanut with three improved varieties of maize, as follows:

- Tropical Zea Extra Early White (TZEEW): erectophilious architecture with 80 days life span,
- Downly Middew Resistant Early Streak White (DMR-ESRW): horizontal canopy, with 120 days life span,
- Obatanpa, a "Quality Protein Maize": *semi-erected* canopy, with 105 days life-span.

Plant density for the three varieties of maize was 4.2 plants/ m^2 while that of the peanut was the same as 2003, 11.1 plants/ m^2. Trials were carried out on ferralitic soil with sandy texture at the surface (0-20 cm) and sandy clay texture at lower depths. The soil fertility was moderate as shown by the following characteristics: pH (H_2O): 6.79, pH (KCl) : 6.18, C_{org} (%) : 1.04, total N (%) : 0.048, available P (ppm) : 55.35 and K^+ (meq/100 g) : 0.51. This fertility was strengthened by the provision of 10 t/ha of mulch from *Cymbopogon nadus* leaves, previously *distillated*. Moreover, 100 kg/ha of fertilizers NPK (10- 20-20) were applied in two stages on 21 and 45 days after sowing (DAS). The plots received natural rainfall and were irrigated as needed to provide the required water to compensate for the estimated potential evapotranspiration (ETP) of 5 mm/day.

Experimental designs

- 2003 growing season

The experimental treatments were three cropping systems, with peanut as subordinate crop and three sowing densities with DMR-ESRW as dominant crop. In addition, there were one plot of peanuts alone and three densities of maize only. Overall, there were seven plots with four replications in randomized complete blocks. The plots size were 3 x 3 m^2

- 2004 growing season

Peanut was intercropped with three varieties of maize: TZEEW, DMR-ESRW, and Obatanpa. The experimental design was a randomized complete block, with five replications. Each block was composed of seven plots: one plot of peanut sole, three plots of maize sole (TZEEW, DMR-ESRW, Obatanpa), and three plots of peanuts intercropped with each of the above three varieties. The plots sizes were 3 x 3 m^2.

Experimental measurements

- Solar radiation measurement

The total solar radiation was measured above the maize and peanut's canopies of the maize and the peanut with a Solar Energy Sensor Data Acquisition System (Type ES, Delta-T Devices). From 22 to 86 DAS, measurements were made weekly in five locations in each plot between 9: 30 am and 11: 30 am.

During the growing season, the level of nebulosity was high. Hence, for each plot, the variation which is inherent in these measurements was corrected by the relative expression of residual radiation value, with the incidental radiation value above the canopy of maize as reference. For other measurements, such as etiolation, gynophore index, dry matter and grain yield, two rows were eliminated on the two lateral boundaries and six median rows were analysed.

- Etiolation measurement

The measurement of the main axis length was used for the calculation of etiolation due to shading.

- Gynophore index measurement

The gynophore index for the axis is calculated as follows : $I = Lp/L_T$, with Lp : length of the part of the axis occupied with pods, and L_T : total length of the axis; one hundred and twenty axes were chosen per plot

- Dry matter and grain yield measurement

Total harvest was weighed for the measurement of total dry matter, vegetative biomass, leaves and grain yields.

Statistical analysis

Variables were subjected to analyses of variance using Statistix 8 (Analytical software Tallahassee); Microsoft Office Excel 2003 was used to calculate regression and correlation in order to determine the relationship between the shading level and different variables. The pair wise comparison using Turkey HSD test and level of signification was also applied.

RESULTS

Availability of solar light on peanut canopy according to the cropping system

In the context of the experiments where water, mineral and organic fertilizers are not limiting factors, the availability of solar light on peanut canopy is the main parameter which determines the efficiency of intercropping systems. During the 2003 growing season experiment, the differentiation of shading was brought out with variation of the sowing density of the same maize variety (DMR-ESRW), while for the 2004 experiment, sowing densities of maize were the same and the differentiation of the shading was provided by diverse maize architecture.

Light levels were recorded from 22 DAS, but differences between peanut sole plots and plots of peanut intercropped with maize, were only observable from 43 DAS (Figure 1). Between 43 and 50 DAS, impact of shading on the peanut canopy started to be different, depending on the variety and /or the sowing density of maize. At 57 DAS, maize growth was maximal and the degree of shading was stable until day 86. During the 2003 growing season, the degree of solar interception was approximately 70 %, 56 % and 53 % for peanut intercropped with maize sown, respectively at densities of 2.5, 3.1 and 4.2 plants/m^2. For the 2004 growing season, the percentage of light interception at the peanut canopy was approximately 72 %, 54 % and 59 % when intercropped respectively with TZEEW, DMR-ESRW and Obatanpa.

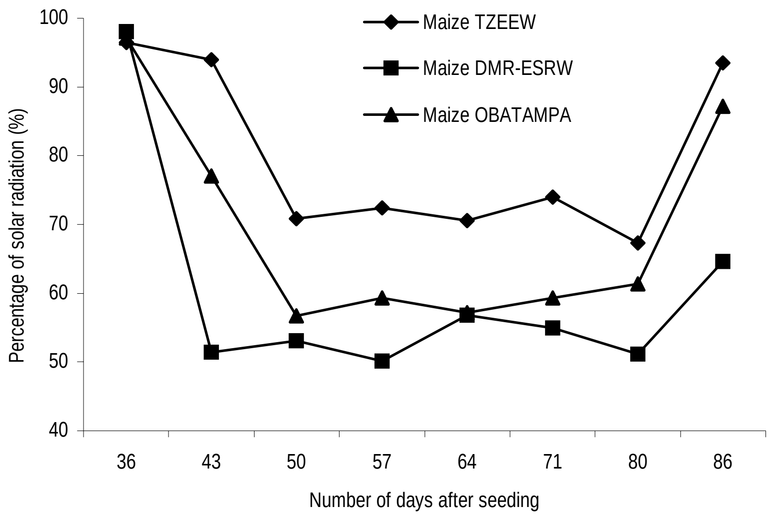

Figure 1: Percentage of solar radiation on the peanut's canopy of intercropped or not with maize varieties (TZEEW, DMR-ESRW, Obatanpa)

From 86 DAS to peanut harvest (90 DAS), the percentage of solar radiation on the canopy of the peanut intercropped with Obatanpa and TZEEW increased respectively to 84 and 95 %. This increase in exposure may be related to partial or total withering of the leaves of these two varieties of maize. On the other hand, during this period, DMR-ESRW leaves were still green and the percentage of the solar radiation above the peanut canopy varied between 60 and 70 % according to the sowing density of maize.

The table 1 shows that the cumulated quantity of solar radiation available for peanut sole during its cycle was almost equivalent for years 2003 and 2004.

This energy received by the plots was divided in two parts. The first one ran from the peanut germination to 36 DAS. The height of maize was low and the shading was not significant. Therefore, the quantity of energy available was considered as initial energy for all plots. This initial energy was estimated at 47.67 x 10^8 kj/ha for the 2003 growing season and at 49.757 x10^8 kj/ha for the 2004 growing season. The second part (specific energy) covered the period running from 36 DAS to the harvest time (90 DAS). The quantity of energy which corresponds to this period, varied according to the variety and the sowing density of maize. The high levels of shading in respect to specific energy were respectively 39 % and 37, 7 % for 2003 and 2004 growing seasons.

Peanut etiolation

Table 2 showed the results of the impact of diverse levels of shading on the peanut main axis.

The analysis of variance shows a highly significant effect of the level of shading on the main axis length. The most important effect was noticed for peanut intercropped with DMR-ESRW, sown at 4.2 plants/m^2. DMR-ESRW is characterized by a planophile canopy. Axes lengths were 22.9 and 24.3 % taller than control respectively during 2003 and 2004 growing season. The effect is moderate with TZEEW, which has an erectophilous architecture. Concerning the Obatanpa variety, the architecture is semi-planophile and the peanut shading induced intermediate etiolation. These results corroborate those dealing with available energy shown in table 1.

Gynophore index

Shading of peanut canopy indeed, induces also the etiolation of all other stems of the plant. It therefore causes the abortion of most of flowers formed along the stems. The number of pods concerned represents about 25 % of total yield (unpublished).

The gynophore index was used to evaluate the degree of flowers and pods abortion. Results from the analysis of variance showed that gynophore index varied very significantly according to the total solar radiation available during the life span of peanut plants grouped cropping systems (Table 3).. Three homogenous groups were identified. The index of peanut intercropped with TZEEW was significantly different from the index of peanut intercropped with DMR-ESRW and Obatanpa. The frequency distribution polygons for both growing seasons showed two main sub-populations, composed of peanut intercropped with the maize and peanut sole (Figure 2).

Table 1: Available energy during the peanut span for 2003 and 2004 growing seasons. (d1, 2,5 plants of maize /m^2 ; d2, 3,1 plants of maize /m^2; d3, 4,2 plants of maize /m^2 (d1, d2, d3 = maize sowing density). DMR-ESRW, Dowly Middew, Resistent Early Streak White; TZEEW, Tropical Zea Extra Early White)

Growing season experiment	Cropping systems (maize density, plants/m^2)	Initial energy (x 10^8 kj/ha)	Specific energies (x 10^8 kj/ha)	Total energy (x 10^8 kj/ha)
2003	Peanut alone	47.67	64.6	112.27
	Peanut -DMR-ESRW (d1)	47.67	51.12	98.80
	Peanut -DMR-ESRW (d2)	47.67	42.46	92.5
	Peanut -DMR-ESRW (d3)	47.67	39.47	87.14
2004	Peanut alone	49.76	65.07	114.83
	Peanut -TZEEW (d3)	49.76	52.29	102.05
	Peanut -Obatanpa (d3)	49.76	44.93	94.68
	Peanut-DMR-ESRW (d3)	49.76	40.5	90.26

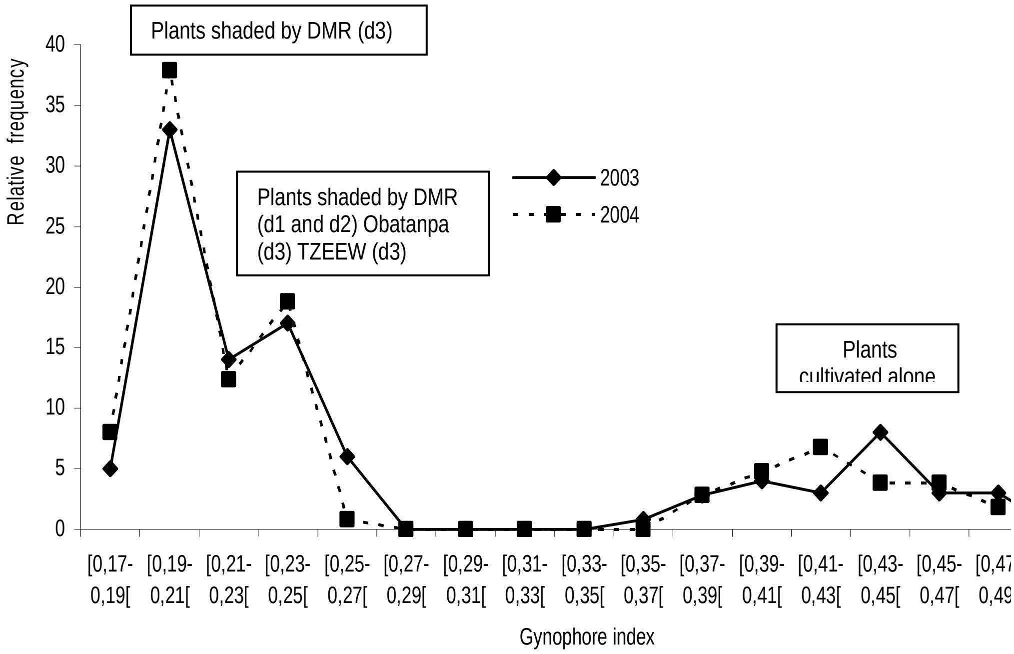

Figure 2: Frequency distribution polygons of gynophore index intercropped or not with TZEEW, DMR-ESRW, Obatanpa. (d1, 2.5 plants of maize/m^2 ; d2, 3.1 plants of maize/m^2 ; d3, 4.2 plants of maize/m^2; d1, d2, d3 = maize sowing density).

Table 2: Main peanut axis length in the 2003 and the 2004 growing seasons. (d1, 2.5 plants of maize /m^2 ; d2, 3.1 plants of maize /m^2; d3, 4.2 plants of maize /m^2 , d1, d2, d3 = maize sowing density; DMR-ESRW, Dowly Middew, Resistent Early Streak White; TZEEW, Tropical Zea Extra Early White).

Growing season experiment	Cropping systems (maize density, plants/m^2)	Main axes length (cm)
2003	Peanut alone	51.8^d
	Peanut -DMR-ESRW (d1)	56.1^c
	Peanut -DMR-ESRW (d2)	59.1^b
	Peanut -DMR-ESRW (d3)	63.7^a
2004	Peanut alone	51.4^c
	Peanut -TZEEW (d3)	56.9^b
	Peanut -Obatanpa (d3)	60.1^{ab}
	Peanut-DMR-ESRW (d3)	63.9^a

a, b, c, d : values followed by different letters in the same column are statistically different (Turkey HSD pair wise comparisons)

Figure 3 shows the relationship between gynophore index and the number of pods grown up along the axis. The first part of the graph with gynophore index ranging from 0.17 to 0.27 represents the plants shaded with maize intercropped with DMR-ESRW, TZEEW, Obatanpa. It is also noticeable that this population was made up of two sub-populations. The second population is more homogenous and was composed of control plants; gynophore index ranged from 0.3 to 0.51. The number of pods grown up along axis showed a strong positive correlation ($p = 0 .01$) with gynophore index ($y = 82.8x – 13.4$; $R^2 = 0.74$). The second part is made up of peanut sole, for which the gynophore index has no noticeable relationship with the number of pods.

Effects of shading on the peanut productivity

Data collected, concerned several parameters of productivity such as total dry matter, vegetative biomass including leaves and stems, leaf production and grain yield (Table 4). These measures are subjected to analysis of variance in order to evaluate the influence of shading induced by intercropping. For both experimental seasons (2003 and 2004), the peanut shading affected these parameters very significantly. The means were separated by Turkey HSD all pair wise comparison test ($p < 0.0001$).

During the 2003 growing season, the total dry matter yield ranged from 7022 kg/ha for peanut sole to 3185 kg/ha for peanut intercropped with the highest density of DMR-ESRW. The equivalent value for 2004 growing season were 7356 kg/ha and 3296 kg/ha. For both experiments, the high shaded plants yielded 55 % lower than the control. Vegetative biomass yield was slightly higher in 2004 growing season than in 2003. Yields ranged from 4992 kg/ha to 2162 kg/ha in the 2003 growing season and from 5192.2 kg/ha to 2222 kg/ha for the 2004 growing season.

The formation and functioning of leaves are basic conditions for plant productivity. There are closely link between the amount of solar radiation available and productivity. As shown in table 4, . shading significantly affected the leaf production. The yield ranged from 1873 kg/ha to 872 kg/ha in 2003 and from 1944 kg/ha to 854 kg/ha. The variation principally depended on the densities and the architecture of maize.

The grain yield is the finality of the cropping and constitutes the parameter which integrates different types of stress to which the plant was subjected to during its life span. In the 2003 growing season, the grain yield ranged from 1601 kg/ha for peanut sole to 780 kg/ha for peanut intercropped with the maximal density of DMR-ESRW. In the 2004 growing season, grain yield was slightly better. It ranged from 1785.4 kg/ha for peanut sole to 812 kg/ha for peanut associated with DMR-ESRW, characterized by a planophile canopy (Table 4). It appears, that peanut yield varied according to the architecture of the maize combined. This architecture depends on the light solar available for peanut during its life span. Figures 4-a and 4-b display a linear regression between the productivity and the solar radiation availability during the peanut life span for these parameters. From these relations, the predicted value when the productivity could be nil, is respectively around 70 x10^8 kj/ha, 72 x10^8 kj/ha for 2003 growing season and 2004 growing season experiments.

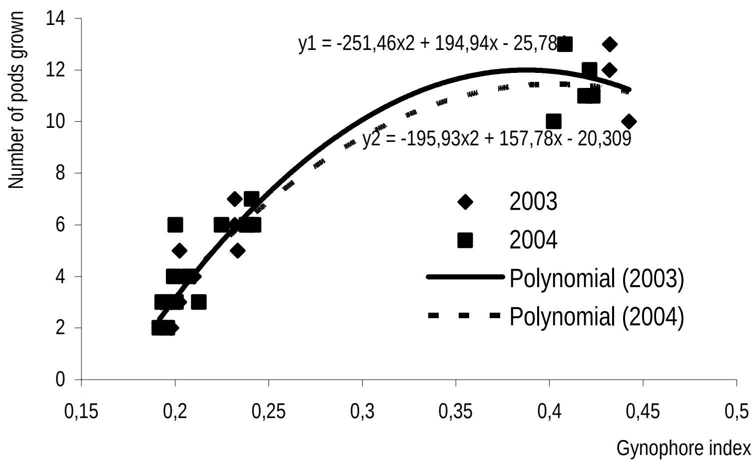

Figure 3: Relationships between number of pods grown up along axis of peanuts and gynophore index

Table 3: Peanut gynophore index in the 2003 and the 2004 growing seasons. (d1, 2.5 plants of maize /m^2 ; d2, 3.1 plants of maize /m^2; d3, 4.2 plants of maize /m^2 , d1, d2, d3 = maize sowing density; DMR-ESRW, Dowly Middew, Resistent Early Streak White; TZEEW, Tropical Zea Extra Early White).

Growing season experiment	Cropping systems (maize density, plants/m²)	Gynophore index
2003	Peanut alone	0.43 a
	Peanut -DMR-ESRW (d1)	0.24 b
	Peanut -DMR-ESRW (d2)	0.206 bc
	Peanut -DMR-ESRW (d3)	0.197 c
2004	Peanut alone	0.42 a
	Peanut -TZEEW (d3)	0.24 b
	Peanut -Obatanpa (d3)	0.201 c
	Peanut-DMR-ESRW (d3)	0.197 c

a, b, c : values followed by different letters in the same column are statistically different at $p < 0.0001$ (Turkey HSD pair wise comparisons)

Table 4: Total dry matter yield, biomass vegetative, leaf yield, grain yield of peanut during the 2003 and 2004 growing season. (d1, 2.5 plants of maize /m^2 ; d2, 3.1 plants of maize /m^2; d3, 4.2 plants of maize /m^2 , d1, d2, d3 = maize sowing density; DMR-ESRW, Dowly Middew, Resistent Early Streak White; TZEEW, Tropical Zea Extra Early White).

Growing season experiment	Cropping systems (maize density, plants/m²)	Total dry matter yield (kg/ha)	Biomass vegetative (kg/ha)	Leaf yield (kg/ha)	Grain yield (kg/ha)
2003	Peanut alone	7022 a	4992 a	1873 a	1601 a
	Peanut -DMR-ESRW (d1)	4684 b	3202 b	1178 b	1129 b
	Peanut -DMR-ESRW (d2)	3626 c	2569 c	984 c	885 c
	Peanut -DMR-ESRW (d3)	3185 c	2162 c	872 c	780 c
2004	Peanut alone	7356 a	5192 a	1944 a	1785 a
	Peanut -TZEEW (d3)	4723 b	3284 b	1253 b	1157 b
	Peanut -Obatanpa (d3)	3684 c	2639 c	1022 c	942 bc
	Peanut-DMR-ESRW (d3)	3296 c	2222 c	854 c	812 c

a, b, c : values followed by different letters in the same column are statistically different at $p < 0.0001$ (Turkey HSD pair wise comparisons)

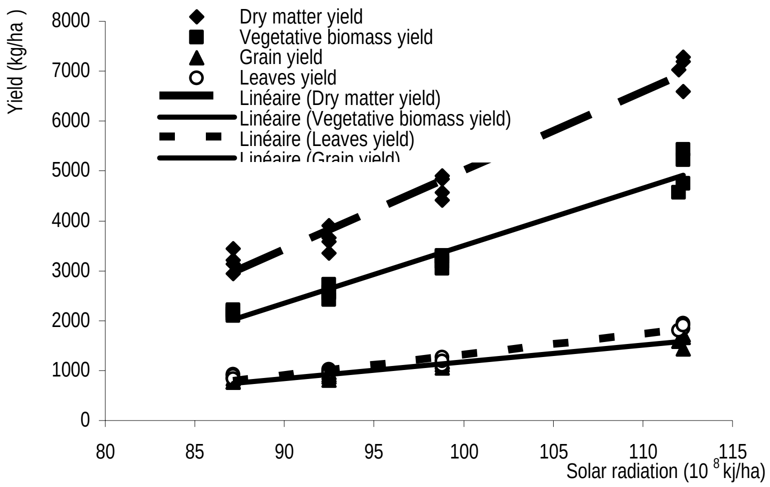

Figure 4 a: Relationships between total dry matter, biomass vegetative, grain, leaves yields and solar radiation available on peanut canopy (2003)

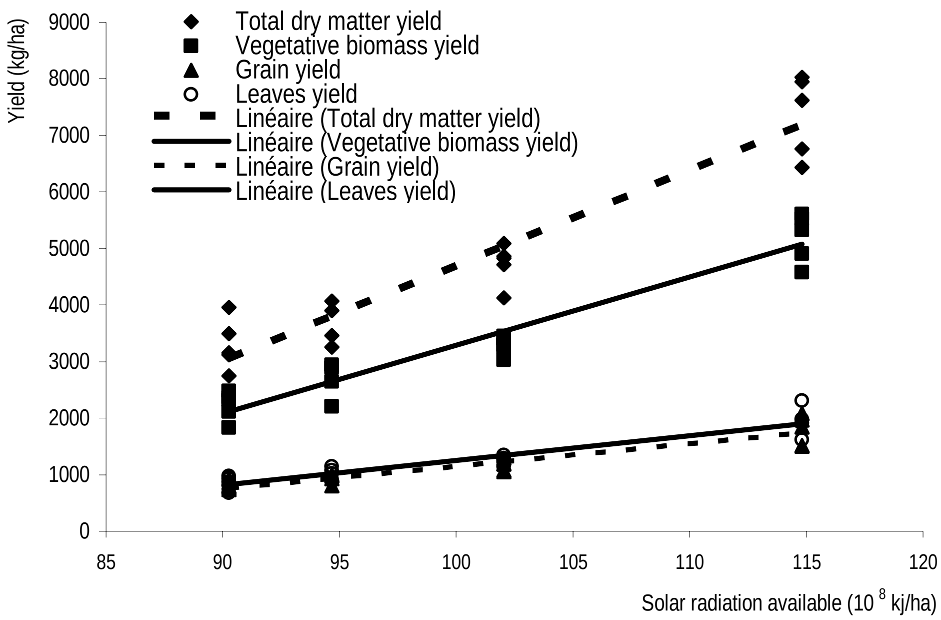

Figure 4-b: Relationships between total dry matter yield, biomass vegetative yield, biomass vegetative yield, grain yield, leaves yield and solar radiation available on peanut canopy (2004)

DISCUSSION

Results of 2003 growing season experiment showed a reduction of 22.4 % of full light, as peanut was intercropped with DMR-ESRW sown at 4.2 plants/m². The reduction of maize density increased the quantity of available energy above the peanut intercropped canopy. But this reduced the potential yield of the cropping system. The purpose of the second experiment, carried out in 2004 was to sow maize with optimal density and to reduce peanut shading by using the architectural difference of diverse varieties of maize. Thus, total productivity of the system was improved (unpublished).

Literature review on competition and intercropping has revealed few indicators dealing with physiological aspects [2]. Etiolation is the most apparent response of plant to lack of light [12, 13]. This physiological reaction of plant to shading is characterized by spectacular elongation of stem and thinner leaves than sun leaves. Under shaded conditions thinner leaves are more efficient to intercept light [13].

In both experiments carried out in 2003 and 2004 growing seasons, etiolation was significantly different according to the level of peanut shading. Plants subjected to 46 % light reduction were 24 % taller than controls in peanut sole plots. For 40 % of light reduction, [10] reported a 30 % increase in height of the main axis of peanuts. It appeared that the peanut variety used by these authors is tolerant to small shading (less than 20%), while the peanut variety used in our experiments displays tolerance to higher shading.

The gynophore index constitutes a synthetic response of the peanut to shading. It covers both development and reproduction phenomena. Gynophore index is remarkably affected by shading. As shown in figure 2, two separated populations are represented.

Even if the photosynthetic efficiency per unit of dry matter is enhanced in shading conditions [13, 14], it remains gap of photosynthetate and the sink demand may be adjusted by floral abortion [12]. The balance between source and sink results in fewer pods being set, but a larger proportion being filled and brought to maturity [10].

Moreover the effect of etiolation on number of pods, shading substantially affects the yields (Table 4). The reductions of biomass and grain yields were significantly correlated with light reduction (Figure 5). The experiment data show that with 46 % of the light reduction, the average of the yield reduction was about 55 %. For a similar percentage of light reduction, [13] observed a 30% reduction of peanut yield. For 40 % of light reduction, [10] reported yield reductions ranging from 26 to 33 %. The large range of percentage yield reduction for an equivalent degree of light reduction could be explained by, the difference of variety, climatic conditions and genetic capability of shading tolerance [15, 16, 5]. It appeared that the peanut, though adapted to growth in full sun, also possessed a full suite of strategies for acclimation to shade [10].

Results showed a close link between the extent of shading and the decrease of dry matter and grain yield (Figure 6). This decrease occurred in several steps. From 0 up to 38 % shading induced usual adjustment of plant to stress, including an exponential decrease phase, a stabilized phase and moderate decrease phase [17]. This sequence corroborates the "S" characteristics evolution of alive tissue adaptation, when subjected to stress, mainly drought stress [18]. Between 38 and 42 % of shading, the productivity slightly increased and then, followed a moderate decrease. This succession of adjustment reaction corroborates the findings on *Elaeis guineensis* (palm tree) adaptation to drought stress [19].

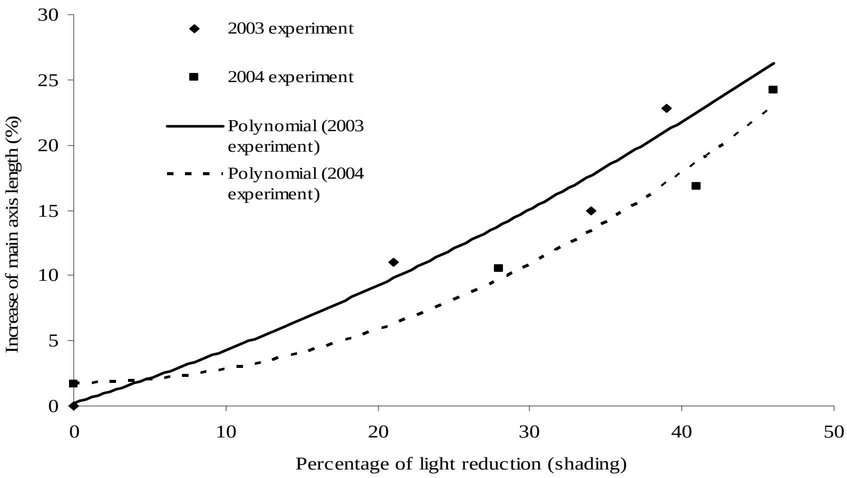

Figure 5: Relationships between increase of main axis length of peanut and the effect of shading (2003, 2004 experiments)

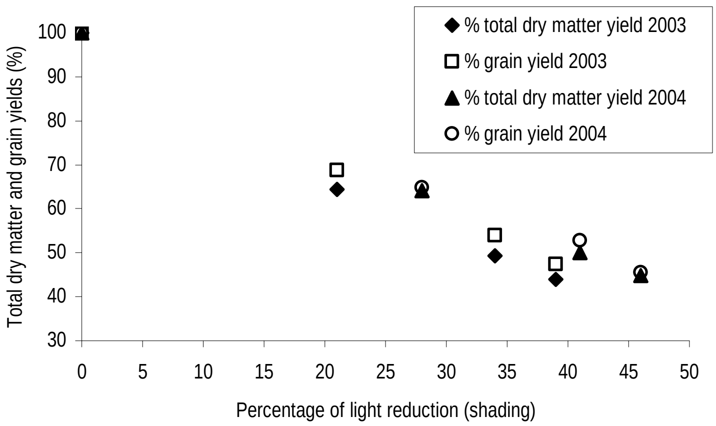

Figure 6: Evolution of the total dry matter and the grain yields with respect to solar radiation available on peanut canopy during the 2003 and the 2004 growing seasons.

CONCLUSION

Intercropping of peanut with various varieties of maize as dominant crop induced etiolation of the peanut as response to shading by the maize canopy. Moreover, a high gynophore index is an indicator of a high number of mature pods along the axis. That was the case of peanut intercropped with TZEEW, a variety of maize characterized by erectophilous architecture. Furthermore the reduction of the light significantly affected the yield of the subordinate crop in the cropping system. An adequate choice of the subordinate crop could contribute to the improvement of the productivity of intercropping systems. Further experimentation is required to achieve this aim.

REFERENCES

1. Kang B. T. and Wilson G. F.1987. *The development of alley cropping as a promising agroforestry technology*. In: Steppler H.W. and Nair P. K.R., (eds). Agroforestry. A decade of development : 227-243.
2. Connoly J., Goma H.C. and Rahim K. 2001. The information content of indicators in intercropping research. *Agriculture, Ecosystems and environment* 87: 191-207.
3. Shikata K., Matsushita Y., Nawata E. and Sakuratani T. 2003. Effect of intercropping with maize on the growth and light environment of cowpea. *Japanese Journal of Tropical Agriculture* 47: 17-26.
4. Awal M. A., Koshi H. and Ikeda T. 2006. Radiation interception and use by maize/peanut intercrop canopy. *Agricultural and forest meteorology* 139: 74-83.
5. Reynolds P., Simpson J., Thevathasan N. and Gordon A. 2007. Effects of tree competition on corn and soybean photosynthesis, growth, and yield in a temperate tree-based agroforestry intercropping system in southern Ontario, Canada. *Ecological engineering* 29: 362-371.
6. Michon G., 1983. *Village forest-gardens in west Java. Proceedings of a consultative Meetings held in Nairobi*, 8 to 15 April 1981. In: Plant research and agroforestry. Editor: P. Huxley. ICRAF Nairobi:13-24.
7. Steiner K. G. 1985. *Cultures associées dans les petites exploitations agricoles tropicales en particulier en Afrique de l'Ouest.* Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) Gmbh et Dag-Hammarskjöld-Weg 1+2 Postfach 5180, D 6236 Eschborn. 347 p.
8. Ohm, H.W., and Nagy, J.G., 1985. *Technologies appropriées pour les paysans des zones semi- arides de l'Afrique de l'Ouest.* Université de Purdue, Indiana. 430 p.
9. Ofori F. and Stern W. R. 1987. Cereal-legume intercropping systems. *Adv. Agron*. 41: 41-90.
10. Barbour J. C., Bridges D.C. and Scott Nesmith D. 1994. Peanut acclimation to simulated shading by weeds. *Agronomy Journal* 86: 874-880.
11. Baumann D. T., Bastiaans L. and Kropff M. J. 2001. Competition and crop performance in a leek-celery intercropping system. *Crop Science* 41: 764-774.
12. Ketring D. L. 1979. Light effects on development of an indeterminate plant. *Plant Physiol.* 64: 665-667.
13. Stirling C. M., Williams J. H., Black C.R. and Ong C. K. 1990. The effect of timing of shade on development, dry matter production and light-use efficiency in groundnut (*Arachis hypogea L.)* under field conditions*. Aust. J. Agric. Res.* 41: 633-644.
14. Regnier E.E., Salvucci M. E. and Stoller 1988. Photosynthesis and growth responses to irradiance in soybean (*Glycine max*) and three broadleaf weeds. *Weed Sci.* 36: 487-496.
15. Glivnish T. J. 1988. Adaptation to sun and shade: a whole-plant perspective. *Aust. J. Plant Physiol.* 15: 63-92.
16. Jinghui L., Zhaohai Z. and Lixin J. 2006. Intercropping of different silage Maize cultivars and Alfalfa. *Cropping patterns and systems* 32:125-130.
17. Turner N. C., 1979. *Drought resistance and adaptation to water deficits in crop plants*. In : Stress physiology of crop plants. Mussel, H., et Staples R.C., (Eds), Wiley Interscience, New York : 343-372.
18. Noy-Meir F. and Ginzburg B. Z., 1969. Analysis of water potential isotherm in plant tissue –II. Comparative studies on leaves of different types. *Austr. Biol. Jour. Scien.* 22: 35-52.
19. Adjahossou D. F. 1983. *Contribution à l'étude de la résistance à la sécheresse chez le palmier à huile* (*Elaeis guineensis Jacq*.). Thèse de Doctorat d'Etat ès sciences, Université Paris 7, 203 pages.