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LIGHT INTERCEPTION AS AN INDICATOR OF LEAF AREA INDEX AND RISK OF DISEASES IN SUNFLOWER

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SUMMARY

Leaf area index (LAI), light interception (LI, %), and frequency of two stem diseases (*Phomopsis helianthi, Phoma macdonaldii*) were assessed for sunflower over two years (1994 and 1995) at Auzeville (southwestern France). The field experiments compared different crop management methods varying in genotype, crop density, N fertilization, fungicide application, and irrigation. A relationship between LI and LAI was proposed and discussed in regard to crop density and growth stages. A close relationship was found between the rate of infection by *Phomopsis* and LI at anthesis in unsprayed plots. This relationship could be used to predict the potential infection as a function of foliar development. The relationship was less obvious with *Phoma*.

Key words: Sunflower, *Phomopsis helianthi*, *Phoma macdonaldii*, leaf area index, light interception, crop management.

INTRODUCTION

Excessive leaf area must be controlled in sunflower to avoid unnecessary soil water depletion, risks of diseases, lodging, and early senescence as a result of self-shading (Merrien, 1992). Maximum yields are currently obtained with leaf area index (LAI) values of 2.5 to 3 at the mid-anthesis stage, but values up to 6 have been recorded under full irrigation (Kiniry et al., 1992). Suitable management could be obtained by combining sowing date, sowing density, N fertilization, and irrigation (Bonari et al., 1992).

Gray stem spot or brown stem canker caused by *Phomopsis helianthi* Munt.-Cvet. *et al.* has been a major sunflower disease in southwestern France since 1984 (Delos and Moinard, 1995). More recently, *Phoma* black stem caused by *Phoma macdonaldii* Boerema kept increasing in the region (Penaud, 1994). *Pho-*

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mopsis severity depends primarily on the susceptibility of sunflower cultivar, plant growth stage, and climatic conditions. In dense stands, plants are more susceptible to attack by this pathogen because of the favourable microclimate (high humidity) and reduced vigour of the plants (Masirevic and Gulya, 1992). *Phoma* sp. seems to react in a similar way, although few studies are available on the disease epidemiology (Penaud and Péres, 1995). In France, no *Phoma*-tolerant genotype is currently available (Penaud, 1994). In southwestern France, drastic yield reductions were observed in fields infected by *Phomopsis*, as a result of rapid leaf senescence, degradation of pith tissue, plant wilting and lodging (CETIOM, 1995). The effects of *Phoma* on sunflower yield could be considered as minor when compared with *Phomopsis*. Early planting, high plant population, and N uptake generally increase the intensity of infection and severity of both diseases (Jinga et al., 1992).

Simple methods have been proposed to assess leaf area at the field level (e.g., Pouzet and Bugat, 1985). Light interception (LI), expressed as a fraction of incident photosynthetically active radiation, has been related to LAI by several authors (Trapani et al., 1988 ; Picq, 1990 ; Orgaz et al., 1992 ; Rachidi et al., 1993). The measurement of the intercepted light during the vegetative period could be a more rapid and dynamic way to characterize a sunflower canopy and to predict a risk of *Phomopsis* and/or *Phoma* development after anthesis.

The objective of this paper is to compare two indicators of crop covering (LI and LAI), and to evaluate the relevance of light interception (LI) for predicting the potential attacks by *Phomopsis* and *Phoma* in sunflower crops differing in management methods.

MATERIALS AND METHODS

A field experiment was conducted at the Agronomic Research Station of INRA in Auzeville, near Toulouse (southwestern France), over two years (1994 and 1995), at a location that is generally favourable for the development of sunflower diseases. The prevailing soil type was a deep silty clay loam averaging 1.6 % organic matter.

1994 - A *Phomopsis*-tolerant genotype (cv. Select) was sown on 2-4 May 1994 following a wheat crop (exp 1), in 0.5 m-rows oriented East-West (Table 1). Plots were 18 x 30 m. Five management options were applied (A: high-input with or without post-anthesis irrigation, B: medium-input with or without irrigation, C: dryland low-input management). Differences in plant population, NPK fertilization, fungicide protection (Punch CS, 0.8 $l.ha^{-1}$sprayed at stage R1) and irrigation were used to create a range of LAI at anthesis and thus a range of susceptibility to *Phomopsis* and *Phoma*. Lateral bands (90 m^2) were kept free of N fertilizer in 1994. Variability was increased by crop rotation (1984-92), soil texture, and soil depth. In addition, an oleic genotype (cv Platon), extremely susceptible to *Phomopsis*, was sown on 4 May and managed under option A (Table 1).

Table 1: Cultural practices on sunflower (1994 and 1995)

Year	Experiment treatment		Genotype	Sowing date	Plant population (plant/ha^{-1})	Nitrogen (kg.ha^{-1})	Fungicides	Irrigation (mm.ha^{-1})
1994	1	A(20)	Select	May 2	69.000	0 / 80	1	85 / 0
		B(33)	Select	May 3	70.000	0 / 60	0	45 / 0
		C(19)	Select	May 4	51.000	0 / 30	0	0
	2	A(1)	Platon	May 4	55.000	80	1	80
1995	3	C(14)	Select	Apr 11	34.000	30	0	0
		A(5)	Select	Apr 19	65.000	75	2 / 3	60 / 0
	4	A(2)	Proleic 204	Apr 19	65.000	75	2	60
	5	B(3)	Santiago	May 2	62.000	50 / 70	1	65 / 85
		C(3)	Asturia	May 2	54.000	0 / 20	0	0

Green leaf area per plant (GLA) was assessed at 3 growth stages (Schneiter and Miller, 1981): early flower bud (R1), beginning of anthesis (R5), and early grain filling (R7) by using the non-destructive method of Pouzet and Bugat (1985):

$$GLA\ (cm^2) = 0.5 *[(l * w * 0.746) *(GL+SYL)] - 0.5 *(l' * w' * 0.746 * SYL) +(GL*30)$$

$$LAI = GLA * PP * 0.0001$$

where-

Length (l) and width (w) of the largest green leaf (in cm)

Length (l') and width (w') of the lowest green leaf (in cm)

GL = number of green leaves

SYL = number of senescent and yellow leaves

PP = plant population (per m^2)

Plant density was observed ten times per plot on 1 m^2 quadrats and one median stage plant per quadrat was assessed for leaf area. Interception of PAR was measured at solar noon in-between rows of four 5 m^2 sub-plots using a hand-held Picqhelios sensor (Picq, 1990). Since senescent leaves and sunflower heads intercept a fraction of incident light, this measurement overestimates the actual efficient IPAR for crop growth.

Symptoms of Phomopsis were observed at the R8 stage (back of head is yellow but bracts remain green) on 10 successive plants at 5 different locations according to the following rating scale (CETIOM, 1995): 0: healthy ; 1: non-encircling spot on the stem ; 2: encircling spot on the stem ; 3: totally brown stem ; 4: stem broken at spot level. The rate of infected plants was defined by the percentage of plants having a grade $\geq$ 1. The number of spots per plant were not counted. A similar approach was used for *Phoma* with only 2 classes (healthy or presence of a dark spot surrounding the petiole).

1995 - Sunflower (cv Select) was sown on 11 (management C) and 19 April (A) on the same plots as in 1994 (exp 3) (Table 1). Two management options were applied (A: high-input with or without irrigation ; C: dryland low-input management). As previously, an oleic genotype (cv Proleic 204), susceptible to *Phomopsis*, was sown on 19 April and managed under option A with or without irrigation around anthesis (exp 4). LAI and LI were assessed at 3 growth stages (R1, R5, and R8) according to the 1994 method. Symptoms of stem diseases were observed during grain filling (R8) as previously described.

An additional large field experiment (1.5 ha) was conducted in 1995 at the same location as a part of a programme on integrated cropping systems. Two management options (exp 5) were adopted using *Phomopsis*-tolerant genotypes (cv Santiago on irrigated B plots; cv Asturia on dryland C plots). The sowing date was 2 May and the sowing arrangement was similar to exp 1 to 4. LAI and LI were measured at 5 growth stages (R1, R3, R5, R6, and R8) in 8 sub-plots (60 m2). Ten plants from each sub-plot were observed at each sampling date for LAI determination. The symptoms of diseases on the stems were noted at R8 according to the 1994 method. LAI, LIE and diseases were measured on the same rows or interrows.

RESULTS AND DISCUSSION

1. Climatic conditions and diseases (Table 2)

1994 - Very wet conditions in the spring (123 mm in April) delayed the sowing time to early May. The soil was at field capacity at that time. The growing season then became very dry except for the rainy spell at the end of June (65 mm) which caused an infection of *Phomopsis* by ascospores (Delos et al., 1995). Temperatures and solar radiation were very high during summer. The sunflower did not suffer from moisture shortage until anthesis (10-20 July), except in shallow plots. The occurrence and progression of Phomopsis was limited by the summer drought and yield losses were lower than in previous years (0.4 $t.ha^{-1}$). The first symptoms were observed on leaves around 18-23 July. In spite of the drought, the progression towards the stem was not completely stopped, but the percentage of seriously affected stems (grade $\geq$ 2) was relatively low (15 % on average with a range from 0 to 70%). Stem break did not exceed 7 % for the high-input irrigated management plots.

1995 - As a result of low spring precipitation and delayed rainfall after sowing, the emergence of the sunflower was poor and irregular when sown early (C, exp 3). Crop density ranged from 18 000 to 52 000 $plants.ha^{-1}$ depending on soil texture and seedbed structure. Since treatment A (exp 3) was sown just before the rain, emergence was quite good. Two emergence dates were observed in exp 5 as a result of short rainy periods and differences in sowing depth. The appearance of ascospores was earlier (mid-June) than in 1994 and first symptoms were observed on the leaves around 10-15 July. But, as a result of low moisture, the leaf contamination was limited, and the disease progression to the stem was retarded by low rainfall and high temperatures from 20 July to early September. At the R8 stage, 77 % of the plots had less than 30% of the stems affected by *Phomopsis* and the attacks were not serious (19 % of plants with grades ≥ 2 in untreated C plots, 3 % in treated plots from exp 4 and 5). However, *Phoma* was more frequent on stems than *Phomopsis*: 85 % of the plots had more than 75 % of the stems affected by this pathogen and 45 % of the plants had symptoms with a grade ≥ 2. No major effects on yield were observed for either disease in 1995.

Table 2: Monthly climatic data (1994 - 1995)

		April	May	June	July	August	September
1994	Rainfall (mm)	123	70	75	11	3	108
	Tmax (°C)	13.9	21.7	24.8	29.3	29.1	22.4
	Tmin (°C)	6.8	11.2	14.5	18.4	17.6	13.0
1995	Rainfall (mm)	38	78	53	67	20	104
	Tmax (°C)	17.9	22.1	24.7	29.3	28.0	21.9
	Tmin (°C)	6.3	10.5	12.8	16.5	16.2	11.1
70-93	Rainfall (mm)	61	94	71	48	57	49
	Tmax (°C)	15.1	18.9	23.1	26.1	25.7	23.0
	Tmin (°C)	6.2	9.5	12.9	14.6	14.9	11.9

2. Comparison of two indicators of crop covering

1) total light interception (LI); and

2) leaf area index (LAI) derived from the Pouzet-Bugat method.

The two indicators generally used in sunflower experiments by French technical and research institutes to assess crop cover were compared.

1994 - The theoretical Beer's law relates light interception (efficiency for growth) to green leaf area index as follows:

$LIsim = a * [1 - exp(-k * LAI)]$

As sunflower has predominantly horizontally oriented leaves, the light extinction coefficient (k) of the crop generally ranges from 0.8 to 0.9. The maximum interception of PAR (a) observed by the authors was 95 to 100 percent. The proportion of PAR intercepted reaches its maximum value for a LAI of between 2.5 to 4.0. The different adjustments suggested by various authors were compared (Picq, 1990 ; Orgaz et al., 1992 ; Rachidi et al., 1993). The relationship proposed by Picq (1990) gave the lowest root mean square error (RMSE), though only slight differences were observed between adjustments (Table 3). The best adjustment (RMSE = 6.9 %) was obtained for values of a = 95 and k = 0.87. The experimental values of LIobs and LAI were plotted in Figure 1 and compared with the value of LIsim.

Table 3: Comparison of equations relating light interception (LI, %) to leaf index (LAI)

$LI_{sim} = a * [1 - exp(-k * LAI)]$

$$RMSE = root\ mean\ square\ error = \sqrt{\frac{1}{n} \cdot \sum_{1}^{n} LI_{obs} - LI_{sim}^{\ 2}}$$

n = 81 experimental data (1994)

Sources	a	k	RMSE (%)
Picq (1990)	95	0.90	7.1
Orgaz et al (1992)	100	0.86	8.1
Rachidi et al (1993)	98	0.83	7.3
adjusted data (1994)	95	0.87	6.9

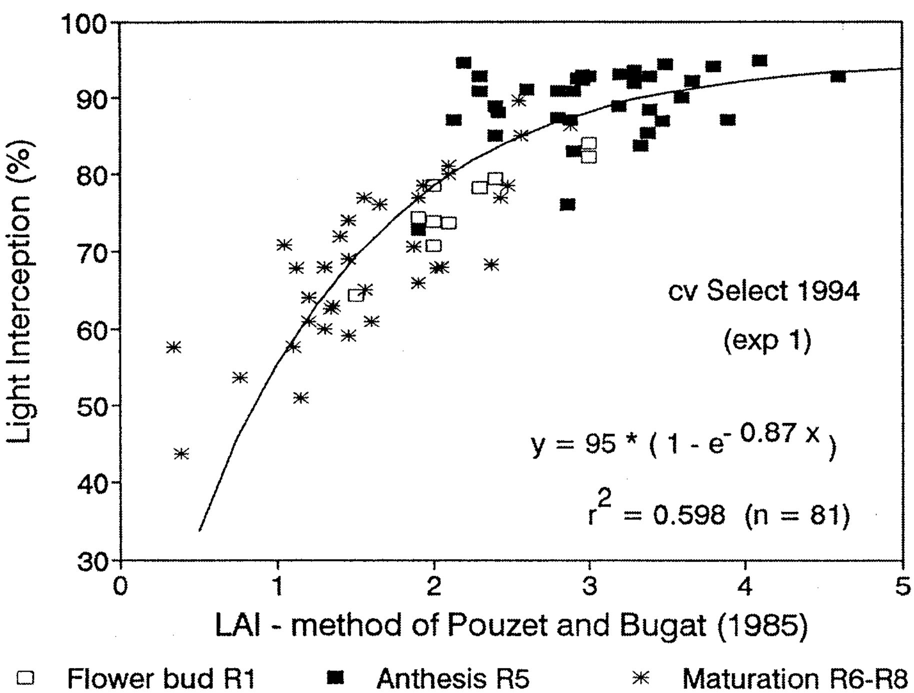

Figure 1. Light interception (LI) as a function of leaf area index (LAI) at 3 growth stages (R1, R5, R8) - cv Select 1994 (exp 1)

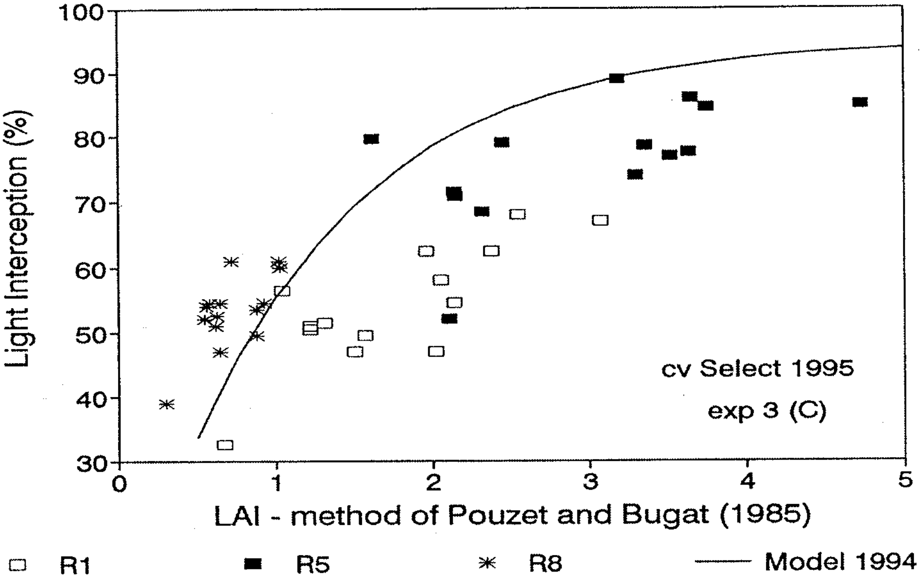

Figure 2. Light interception (LI) as a function of leaf area index (LAI) at 3 growth stages (R1, R5, R8) - cv Select 1995 (exp 3)

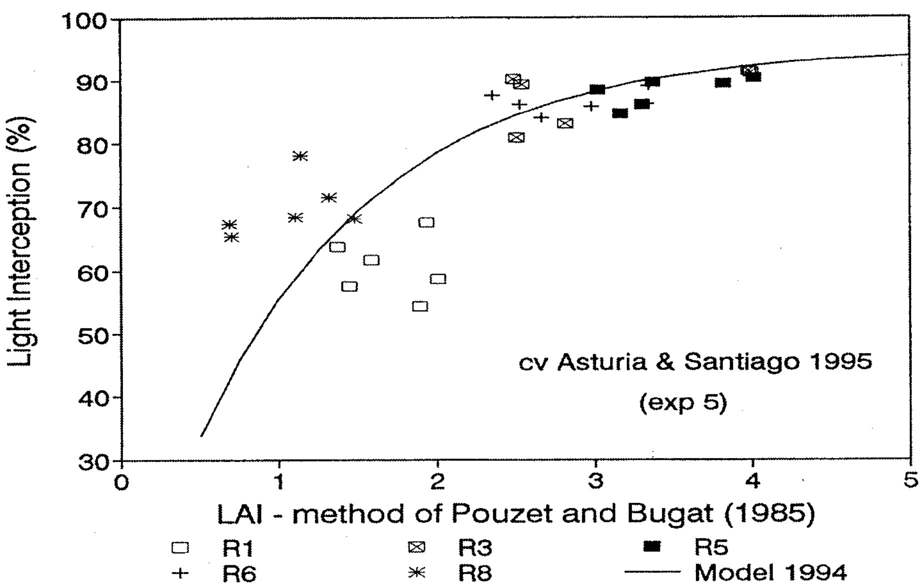

Figure 3. Light interception (LI) as a function of leaf area index (LAI) at 5 growth stages (R1, R3, R5,R6, and R8) - cv Asturia (tall) and Santiago (short) 1995 (exp 5)

The LI-LAI relationships observed in the pre- and post-anthesis periods did not differ significantly and the same equation was acceptable throughout the crop cycle. As only green leaves (i.e., green area > 50 %) were considered for LAI, certain discrepancy with the model was observed in situations where senescence had just started because the yellow leaves, though horizontal and light intercepting, were not considered for green LAI (Figure 1). When senescence was more advanced, the leaves were not efficient in PAR intercepting, but the height of stems probably changed the light interception pattern. This could explain the dispersion of experimental points around the fitted curve for low LAI values (stage R8). A similar conclusion could be drawn from the results of Zaffaroni and Schneiter (1989) and Leterme et al.(1991).

1995 - This general model was tested in 1995 using data from exp 3 and 5, which differed in plant population and/or genotype (plant height). When the sunflower population was small and irregular (exp 3), the model did not represent the experimental data at early flower bud and anthesis (Figure 2). Lower LI values were measured at a given LAI. There may be two reasons for this: 1) LI was measured dynamically by including areas where plants were missing whereas LAI was measured on areas sufficiently covered ; 2) a sparse stand was not so efficient at capturing light as in a regular one because more self-shading was observed (k was reduced). At the stage R8, when the canopy was senescent, the relationship was similar to that observed in 1994. The distribution of the experimental points was closer to 1994 in exp 5 (Figure 3), as a result of higher and more regular plant population. At R1, LI was apparently overestimated by the model as in 1994. From R3 to R6, the observed data generally fitted the model. As previously discussed, values at R8 were underestimated by the model.

In conclusion, LI could be used as a good indicator of green LAI in a range of sunflower management and growth stages. A better prediction is expected for LAI > 2. Low LAI corresponds to 3 different situations: irregular plant population (exp 3), young plants (R1) and senescent plants (R8). Zaffaroni and Schneiter (1989) found that k decreased as LAI increased until a steady phase was reached for LAI at about 2. Picq (1990) had a better fit for LAI > 1.5. In addition, the Pouzet and Bugat method used to estimate that LAI should be tested for a range of genotypes, because of differences in plant height, leaf shape and leaf position on the stem. The leaf age may also change the allometric coefficient (0.746) used in the GLA equation (Merrien, pers.com). Pouzet and Bugat (1985) indicated that in the early stages, at the time of maximum LAI, and under conditions of drought which affect the upper leaves, the method lost some accuracy. However, the assessment of LAI for crop management (irrigation, prediction of diseases) is determinant from early bud to anthesis and could be reasonably predicted by LI.

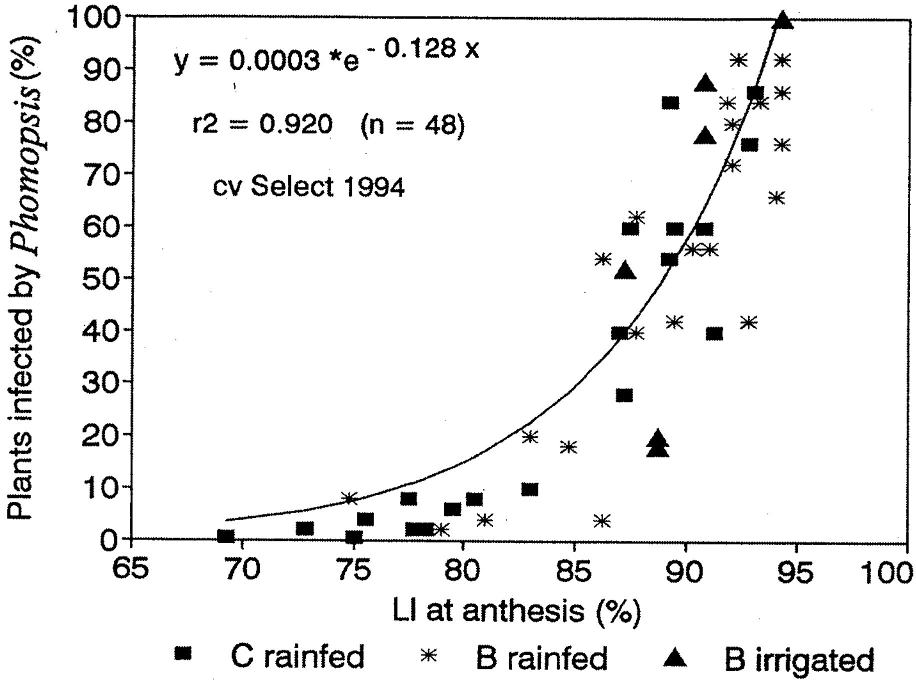

Figure 4. Proportion of plants infected by Phomopsis as a function of light interception (LI) at anthesis (R5) in unsprayed plots - cv Select 1994 (exp 1)

3. Light interception (LI) as an indicator of the risk of diseases

The frequency of stems attacked by *Phomopsis* was plotted against the light interception in 1994 (Figure 4). Only the 52 unsprayed plots (exp 1, B and C) were considered to establish the relationship. An exponential law was fitted to the observations (r_2 = 0.920). The rate of infection increased with LI. A rapid increase in the rate was observed for LI exceeding 85 % at the anthesis stage (i.e., LAI > 2.5). The amount of nitrogen (soil and fertilizer) and plant population were responsible for the excessive LAI, which resulted in higher humidity under cover. One irrigation just after anthesis (B) did not favour the propagation of the pathogen. With low-input management (C), the range of LI varied widely, reflecting the importance of initial soil fertility (lower N residue on silty soils). Even with a *Phomopsis*-tolerant genotype, the frequency of attacks (up to 100 %) was high when high crop density, high N fertilization, and irrigation were added together without fungicide. Masirevic and Gulya (1992) indicated that population densities < 50 000 plants.ha^{-1} and N fertilization < 60 kg.ha^{-1} are necessary to decrease the incidence of this disease. In addition, these authors indicated that on susceptible genotypes, stem lesions may eventually reach 15 to 20 cm, while on the stems of tolerant genotypes the lesions remain small and superficial. Differences in yield loss are found between genotypes, but the frequency of infected plants (i.e., grade ≥ 1) is probably not significantly different.

A similar relationship was observed for *Phoma* (r_2 = 0.860). The frequency of stem spots did not exceed 50 % (Figure 5). The attacks were limited by the presence of *Phomopsis* earlier in the season and some antagonism could have played a part in 1994. Since the two pathogens react similarly to population environment, the rate of *Phoma* increases with *Phomopsis* until a frequency of 50 % of the plants infected by *Phomopsis*. The highest rates of infection by *Phoma* were observed in plots where sunflowers were frequently grown from 1984 to 1992.

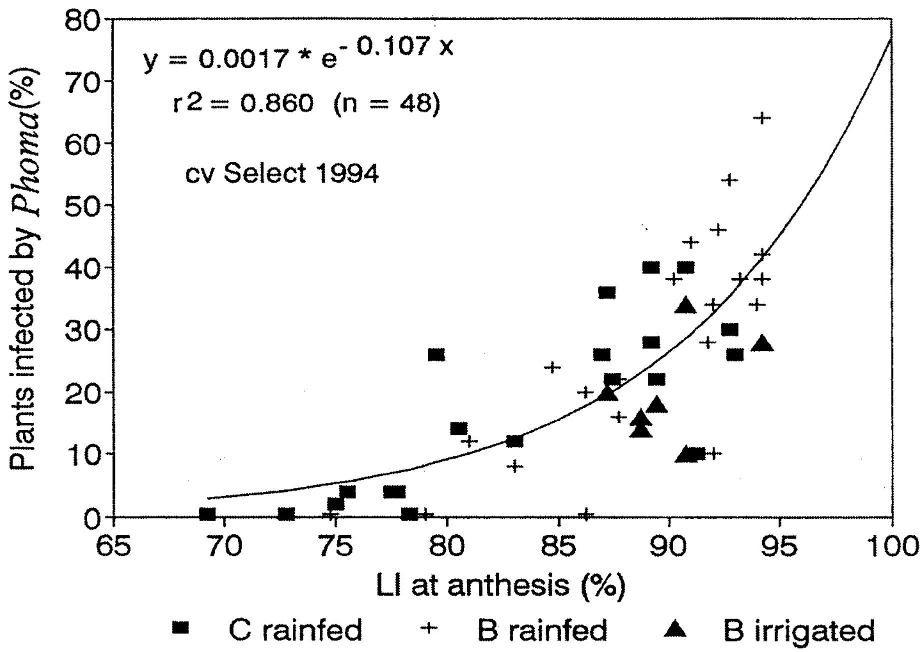

Figure 5. Proportion of plants infected by Phoma as a function of light interception (LI) at anthesis (R5) in unsprayed plots - cv Select 1994 (exp 1)

The two relationships were used to specify the potential risk of diseases. The development of spots depends on the climatic conditions after anthesis. The prediction of the rate of infected stems could not be used to directly evaluate yield loss. Non-linear models were used to evaluate the different management options in 1994 and 1995. In 1994, the medium-input plots (B) suffering from drought before anthesis (shallow soils) were not affected by *Phomopsis* because of the rapid leaf senescence that stopped the pathogen's progression towards the stem (Figure 6).

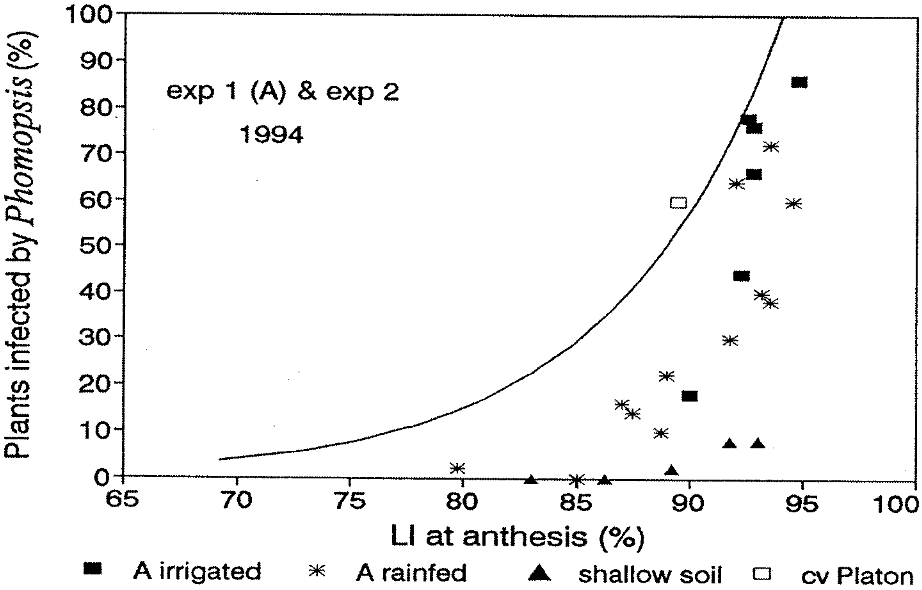

Figure 6. Proportion of plants infected by Phomopsis as a function of light interception (LI) at anthesis (R5) in fungicide-sprayed plots and shallow soil situations - cv Select and Platon 1994 (exp 1 & 2)

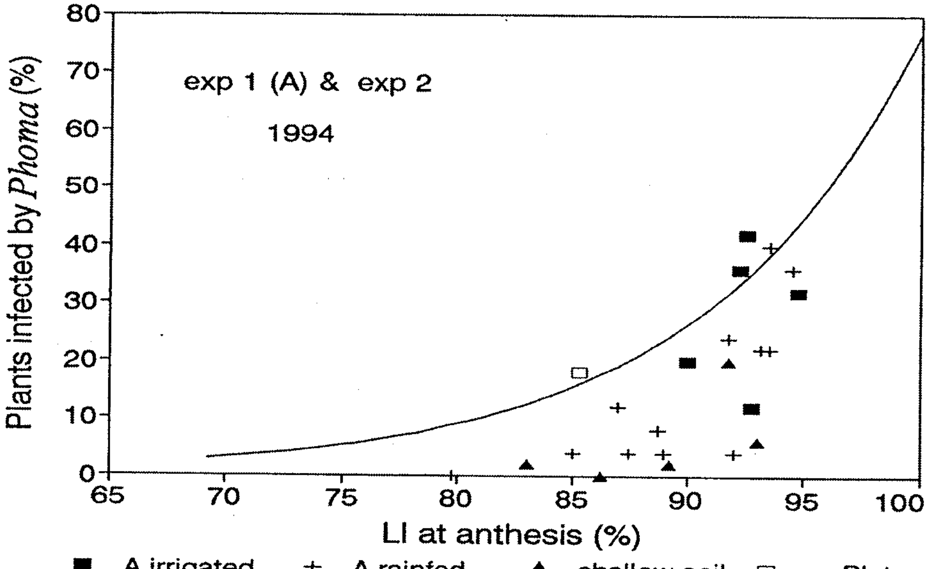

Figure 7. Proportion of plants infected by Phoma as a function of light interception (LI) at anthesis (R5) in fungicide-sprayed plots and shallow soil situations - cv Select and Platon 1994 (exp 1 & 2)

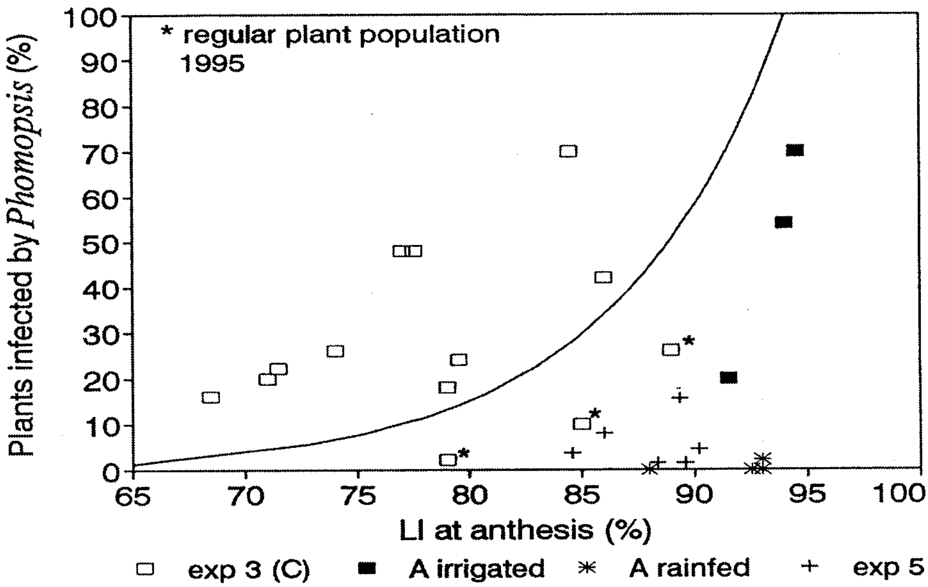

Figure 8. Proportion of plants infected by Phomopsis as a function of light interception (LI) at anthesis (R5) for different 1995 situations - cv Select, Proleic 204, Asturia and Santiago (exp 3, 4 & 5)

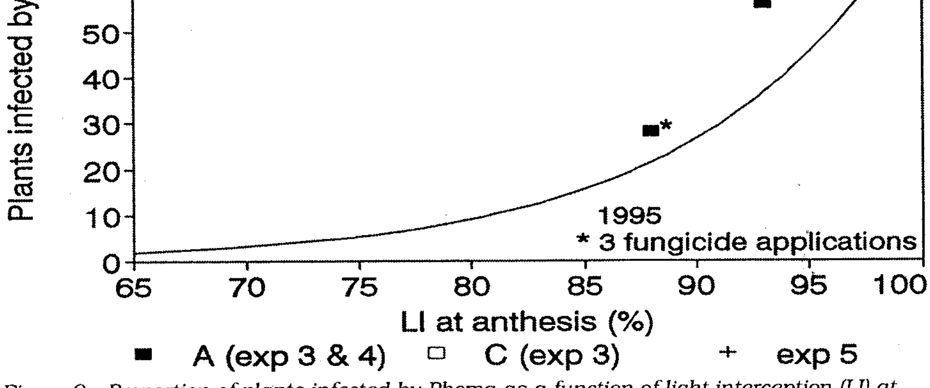

Figure 9. Proportion of plants infected by Phoma as a function of light interception (LI) at anthesis (R5) for different 1995 situations - cv Select, Proleic 204, Asturia and Santiago (exp 3, 4 & 5)

In unirrigated and fungicide-treated plots (A management), *Phomopsis* propagation was limited, compared with untreated B plots. When A plots were irrigated twice after anthesis, the effect of the fungicide was reduced because of a more rapid propagation of the pathogen under leaf cover. The oleic genotype (cv Platon), extremely susceptible to *Phomopsis*, reacted like an unsprayed tolerant genotype, in spite of one treatment. Similar conclusions are drawn for *Phoma* (Figure 7).

In 1995, in spite of low values of LI at R5 (low crop density), high rates of infection by *Phomopsis* were observed in unsprayed plots (exp 3, C) (Figure 8). Three possible explanations are: 1) LI underestimates the actual crop covering by including areas without crop ; 2) the preceeding sunflower crop probably increased the amount of the inoculum supplied by shallowly buried infected stalks (Masirevic and Gulya, 1992) ; 3) the early sowing date might have increased the disease infection (CETIOM, 1995). The first hypothesis is the most probable explanation because when the crop density was higher (>35 000 plants.ha^{-1}) and more regular, a lower infection rate was observed (Figure 8) in spite of a higher LI value. Only plots where several factors favouring disease propagation were present (susceptible genotype, irrigation, sunflower as previous crop) were significantly affected by *Phomopsis* in 1995. The proportion of plants infected by Phoma was very high in 1995 irrespective of LI (Figure 9). The lowest infection rate was found in a situation where three applications of Punch CS were done, while two applications only slightly reduced the disease's progression. The low infection rate by *Phomopsis* was probably responsible for the high frequency of *Phoma*. The latter pathogen could have a lower dew point requirement than *Phomopsis* for stem infection and a longer period of infection.

CONCLUSIONS

The dynamic assessment of LI using a hand-held light sensor is an easy way to represent the spatial variability of a sunflower field more rapidly than directly measuring LAI. Besides, LI is a significant indicator of LAI between stages R3 and R6. As suggested by Picq (1990), LI-based objectives could be defined to better manage the crop. Since LAI at the early bud stage and at anthesis are generally related, the early measurement of LI could be helpful in decision-making with respect to irrigation and fungicide protection. The close relationship between the rate of infection by *Phomopsis* and LI at anthesis in unsprayed plots could be used to assess the potential risk of infection as a function of leaf area development in situations where the pathogen is anticipated. The disease development and severity depends primarily on the amount of inoculum in soil, susceptibility of the sunflower cultivar, plant growth stage, and climatic conditions (Masirevic and Gulya, 1992). The relationship should be tested in situations of more intense disease pressure as in 1992 and 1993 and with genotypes differing in susceptibility to the pathogen.

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INTERCEPTION DE LUZ COMO INDICATOR DEL INDICE DE AREA FOLIAR Y RIESGO DE ENFERMEDADES EN GIRASOL

RESUMEN

El indice de area foliar (LAI), interception de luz (IL, %), y la frecuencia de incidendia de dos enfarmedades del tallo (*Phomopsis helianthi, Phoma macdonaldii*) fueron investigados en girasol durante dos anos (1994 y 1995) en Auzeville (Sudoeste de Francia), en un experimento de campo effectuado para comparar metodos de manajo de cultivo incluyendo variaciones de genotipo, densidad de siembra, fertilizacion nitrogenada, aplicacion de fungicidas, y riego. Una relation entre IL y LAI fue propuesta y analizada de acuerdo con densidad de siembra y estado de desarrollo del cultivo. Una estrecha relacion entre la tasa de infeccion por *Phomopsis* y IL en antesis se encontro en parcelas no fumigadas, la cual podria ser usada para predecir el potencial de infeccion del desarrollo foliar. La relacion no fue tan obvia con *Phoma*.

L'INTERCEPTION DE LA LUMIÈRE, UN INDICATEUR DE L'INDICE FOLIAIRE ET DU RISQUE DE MALADIE CHEZ LE TOURNESOL

RÈSUMÈ

L'indice foliaire (LAI), l'interception de la lumière (LI, %) et la fréquence de plantes attaquées par 2 maladies de la tige (*Phomopsis helianthi, Phoma macdonaldii*) ont été mesurés sur tournesol au cours de 2 années (1994 et 1995) à Auzeville (Sud-Ouest de la France) dans le cadre d'un essai au champ comparant différents itinéraires techniques. La conduite culturale variait par le génotype, la densité de peuplement, la fertilisation azotée, l'application de fongicides et l'irrigation. Une relation entre LI et LAI est proposée et discutée en fonction de la densité de peuplement et du stade phénologique du tournesol. Une relation étroite est établie entre le taux de plantes présentant des symptômes d'attaque par le *Phomopsis* et l'interception de la lumière (LI) au début de la floraison (stade R5) dans les parcelles ne recevant pas de fongicides. Cette relation pourrait servir à préciser le risque d'extension de la maladie pour un état de développement de la surface foliaire. Cette relation ne semble pas aussi robuste avec le *Phoma*.