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EFFECT OF WATER-NITROGEN INTERACTIONS ON LEAF AREA AND YIELD COMPONENTS OF SUNFLOWER

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SUMMARY

As the leaf area expansion and the foliar regression are governed by the sunflower water and N status, the interactions of these factors on leaf area index (LAI) and duration (LAD), and their relationships with yield components, are studied in a field experiment involving different soil depths, N fertilizations and irrigations and two hybrid cultivars. The plants were allowed to take up 100 to 470 $kg \cdot ha^{-1}$ N, and 200 to 700 mm of water; they were free of any diseases or lodging. Twenty-five typical plants per plot were tagged at the 12 leaves stage, and some of them were sampled at the stages: bud apparition, beginning and end of anthesis, and maturity, for measurements of dry matter and N content in leaves, stems and heads. Yields vary from about 1.5 to 4.5 $tons \cdot ha^{-1}$; N supply mainly affects the number of achenes per head and their protein content; water has a strong effect on this number, on the average weight of achenes and on their oil percentage. The LAD is chiefly dependant on the water regimen, with some modulation according to N availabilities. A LAI of about 2.5 is sufficient for the maximum growth of the shortest hybrid, the taller one requiring roughly 4. From the stage of bud enlargement, the number of achenes is strongly correlated both with LAI and the N content in leaves and stems. The average weight of achenes is well-correlated with LAI beyond anthesis and then with the available water. N mainly determines the potential number of achenes at early stages, and water their setting and filling, with a predominant effect on LAI and LAD.

INTRODUCTION

An adequate interception of light energy being the essential factor of photosynthesis and growth, the yield of sunflower is generally linked to the evolution of leaf area along the cycle of development (BLANCHET et al., 1985; MERRIEN, 1988a). A leaf area index (LAI) of 2.5-3 is often sufficient (PICQ, 1988), an excess of foliage increasing the sensitivity to diseases and sometimes to lodging, but in many conditions this optimum LAI can not be reached or it is reached too late, or not maintained during grain filling.

The leaf expansion and the foliar senescence are recognized as dependant on water balance (MERRIEN et al., 1981; RAWSON and TURNER, 1982, 1983) and on nitrogen nutrition (BLANCHET et al., 1987a; MERRIEN et al., 1988b). N also affects florets differentiation (STEER et al., 1984; PALMER and STEER, 1985). But the interactions of water and N and their effects on the leaf area evolution, and also on achenes setting and filling, are not quite clear.

With purpose of modeling the effects of pedoclimatic factors and cultural practices on sunflower growth and yield (QUINONES et al., 1990; TEXIER et al., 1990), we tried to precise in current field conditions some aspects of these interrelations. The main results of an experiment involving various soil depths, N fertilizations, irrigations, and two different cultivars, are then briefly described here. In a range of yields from about 1.5 to 4.5 tons $\cdot$ ha^{-1}, the leaf area variations were related to yield components, elaborated under various water and N availabilities.

MATERIALS AND METHODS

This study was set up in a fine, mixed, mesic Haplustalf soil (27% clay, 40% sand, 1.8% organic matter) at the INRA Station near TOULOUSE in southwestern FRANCE (about 44° northern latitude). The experimental field presents a strong gradient of soil depth accessible to roots, which varies from 0.6 to 1.8 m, involving available water reserves of 120 to 350 mm, and a stock of mineral nitrogen at the planting time of 100 to 200 kg $\cdot$ ha^{-1}. In order to obtain a large differentiation of plots, 0,90 or 270 kg N $\cdot$ ha^{-1} were aplied just before sowing, and irrigations of 0, 150 mm around anthesis and 300 mm throughout the cycle were supplied by sprinklers. All these treatments were managed on the typical soil depths with 3 replicates for each cultivar, on plots of 15x3 m. Then plants were allowed to take up 100 to 470 kg $\cdot$ ha^{-1} N and 200 to 700 mm water; the maximum evapotranspiration of the crop was about 850 mm for the whole cycle on this site.

Two hybrid cultivars, Pharaon of moderate height and TN15 (NSH 15) which is taller, were planted at 8 plants $\cdot$ m^{-2} on April 24. A severe drought followed, with sporadic rainfalls on May 22, June 9, July 6 and August 28. The physiological maturity occurred for both cultivars from August 12 to 25 according to the treatments. No noticeable symptoms of diseases appeared, and the plants were free of any attack or lodging.

At the 12 leaves stage, 25 typical plants selected for height, stem diameter and environment homogeneity were tagged in one plot of each treatment. On 6 of these tagged plants, leaf area was measured by the non-destructive method of POUZET and BUGAT (1985) at intervals of about 10 days all along the cycle, and their heads were examined at maturity according to PALMER and STEER (1985) for the number of rows and achenes per row, average weight and composition of achenes, etc. At the successive stages bud apparition ("star stage"), beginning and end of anthesis, other 4 tagged plants were harvested and sampled to measure the dry weight and N content of leaves, stems and heads. The same sampling was made at maturity on 10 plants, including the 6 used for continuous leaf area measurements. A combine harvest was practiced in all plots.

RESULTS

1) *Yields and components.* As the behaviour of the two cultivars is rather similar, Table 1 indicates these data for the various availabilities of water and N. In the non-irrigated shallow soil, where growth and yield were poor, N fertilization has no effect: the main limiting factor is water which strongly restricts the number of achenes, their average

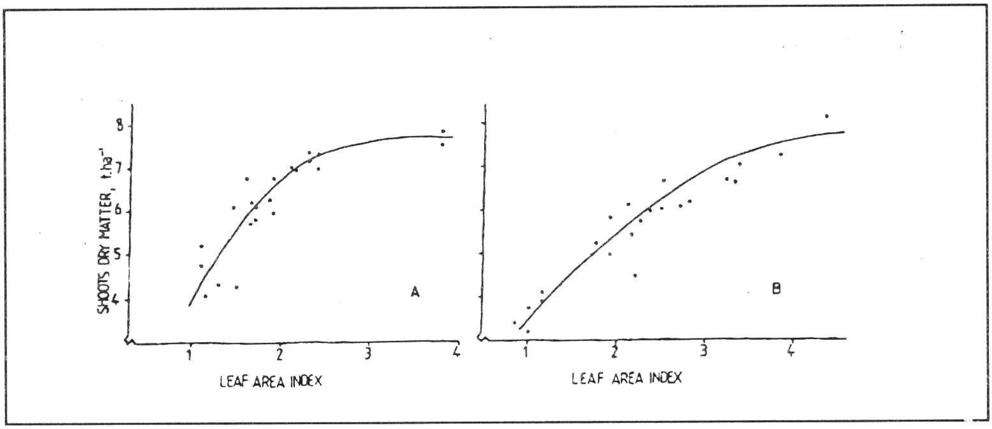

Figure 1 - Above-ground dry matter at anthesis as function of leaf area index A: Pharaon; B: TN 15

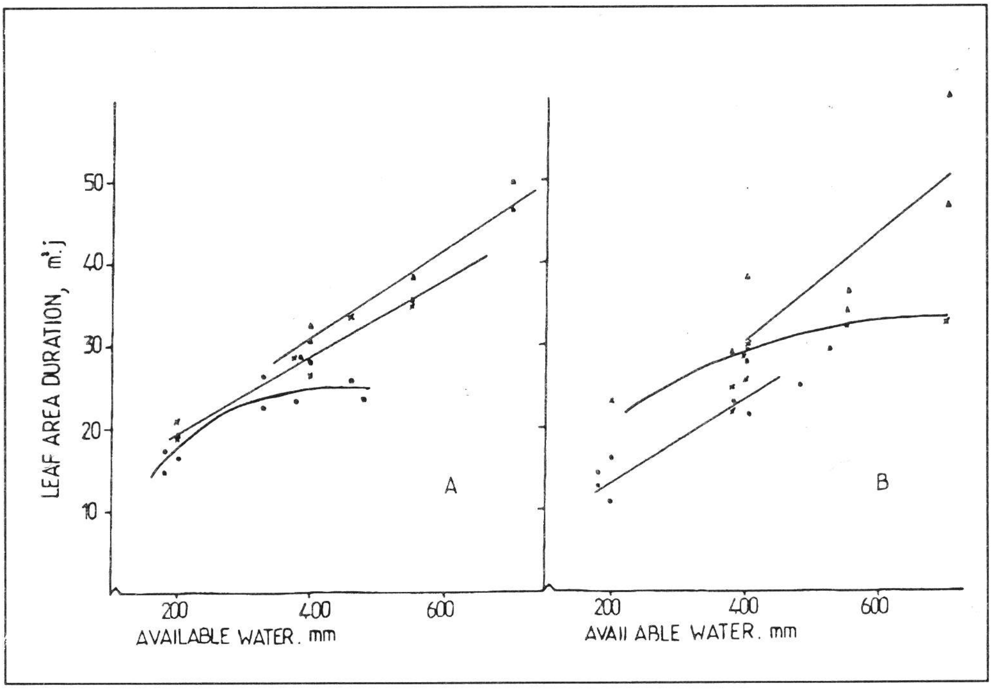

Figure 2 - Leaf area duration per plant as function of available water during the cycle, at three levels of available N: = 100-200 kg · ha^{-1} x 100-200 kg · ha^{-1}; 200 kg · ha^{-1}

weight and oil synthesis. As water availability, growth and yield increase, the effect of N on the number of achenes and their protein content becomes evident, their average weight and oil proportion being mainly governed by water.

Table 1: Yields and components in some typical water and N availabilities

Irrigation		0		150 mm around anthesis		300 mm all cycle	
Shallow soil:	Available water,mm	200		380		460	
	N fertilization,kg · ha^{-1}	0	90	0	90	0	90
	N in shoots,kg · ha^{-1}	105	97	86	134	80	170
	D.M. in shoots,g · plant^{-1}	57.7d	64.8cd	78.0cd	83.6c	113.5b	141.0a
	Achens,g · plant^{-1}	18.9c	18.0c	22.9c	26.2c	39.0b	49.8a
	Number of achenes · plant^{-1}	610c	635c	815b	905b	903b	1155a
	Average weight of achenes,g · 0^{3}	28.5b	28.1b	28.2b	29.0b	41.5a	43.4a
	Oil,%	45.9	46.2	47.6	47.9	51.6	49.3
	Proteins,%	19.7	19.5	15.8	20.3	13.8	16.8
Deep soil:	Available water,mm	400		550		700	
	N fertilization,kg · ha^{-1}	0	90	0	90	0	90
	N in shoots,kg · ha^{-1}	131	177	200	272	160	265
	D.M. in shoots,g.plant^{-1}	90.5c	116.8c	133.2cd	190.6a	139.6c	163.3b
	Achens,g · plant^{-1}	26.8c	40.2b	45.9b	56.3a	44.0b	57.6a
	Number of achenes · plant^{-1}	800b	1060b	1034b	1385a	1025b	1320a
	Average weight of achenes,g · 10^{3}	32.4b	38.4a	44.3a	41.2a	43.1a	43.5a
	Oil,%	45.2	47.0	47.6	50.9	50.4	49.7
	Proteins,%	17.5	19.4	18.0	19.4	17.3	19.1

a, b, c: significant differences in Newman-Keuls test 5% in each soil.

2) *Leaf area, growth and yield components*

a) *LAI and growth of the vegetative apparatus.* Figure 1 presents the weight of shoots as function of LAI for the two cultivars at the beginning of anthesis. As indicated by PICQ (1988), Pharaon has a maximum growth when its LAI reaches about 3; TN 15, the taller cultivar, seems to take advantage of a higher LAI, probably about 4, and its growth is more restricted by low LAI of 1,5-2. This very vigorous variety appears sensitive to certain environments.

b) *Effects of water and N on leaf area.* Figure 2 indicates the leaf area durations (LAD) as function of available water, for 3 levels of N resources (mineral N in soil + N fertilization). The water regimen has the strongest influence on the LAD of both cultivars, the level of N only modulating this quite predominant effect. Such results are

Table 2: Correlations between yield components and leaf area index at successive stages

CHARACTER	LAI at the stages: Star	Bud 4 cm	Begin. anthesis	End anthesis
Number of achenes · plant^{-1}:				
Pharaon	0.36NS	0.69**	0.86**	0.85**
TN15	0.33NS	0.79**	0.89**	0.88**
Average weight of achenes:				
Pharaon	0.37NS	0.53*	0.67**	0.74**
TN15	0.05NS	0.64**	0.79**	0.84**
Yield:				
Pharaon	0.41NS	0.66**	0.85**	0.90**
TN15	0.24NS	0.59**	0.77**	0.82**

NS: not significant. Significant 5%: *; 1%: **.

obtained in homogeneous plant populations of 8 plants$\cdot$m^{-2}; by variations of plant population,and consequently of the intraspecific competition, greater effects of N in various water availabilities were observed by BLANCHET et al. (1987). Then the N-water interactions may depend on competition. In the tested plant population, we state that LAD is mainly dependant on the water regimen, rather than on the N nutrition. Obviously, the periods of water stress can affect this general behaviour, but here the irrigations applied around anthesis do not lead to distinguishable traits between the non-irrigated and the fully-irrigated treatments.

c) *LAI and yield components*. Table 2 indicates the correlations between the LAI and yield components of both cultivars for successive stages. No significant correlations exist at the star stage; TN15 seems even more independant than Pharaon at this early period, where the soil reserves furnish the main requirements. As soon as the bud reaches the size of 4 cm, rather high correlations appear with the numbers of achenes, and they further strengthen during anthesis. For the parameter of the average weight of achenes, high linkages take place around anthesis, and of course it is the same for the yields. Then, from the bud enlargement, the achenes setting seems quite dependant on the plant water status, leaf area and growth. The achenes filling, governed by both late assimilation and assimilates redistributions, becomes sensitive a little later.

Table 3: Correlations between yield components and N content (% D.M.) of leaves and stems at the stages of bud apparition and beginning of anthesis. Same symbols as in Table 2.

Yield component	Star stage		Begin. anthesis	
	Leaves	Stem	Leaves	Stem
Number of achenes. plant^{-1}:				
Pharaon	0.74*	0.74*	0.64**	0.54*
TN15	0.47NS	0.62*	0.48*	0.59**
Average weight of achenes:				
Pharaon	0.41NS	0.35NS	0.41NS	0.35NS
TN15	0.20NS	0.20NS	0.20NS	0.12NS

d) *N content in vegetative organs and yield components.* The correlations between yield components and N content in leaves and stems at the stages of bud apparition and early anthesis are indicated in Table 3. According to STEER et al. (1984), in our case, it is rather the N status in the stem than in the leaves for TN15, and this linkage is enforced at anthesis. No significant relationship exists with the average weight of achenes: as we stated above, it is mainly governed by water, whereas achenes setting is both linked to the foliage extent and activity and to the N status of tissues.

DISCUSSION AND CONCLUSIONS

This experiment first confirms and precises previous data (BLANCHET et al., 1987 a, b); if both water and N are essential for leaf growth and survival, in current agricultural conditions the impact of water balance is predominant. In modeling sunflower growth and production (QUINONES et al., 1990; TEXIER et al., 1990), a careful estimate of water stress repercussions on leaf area and light interception is then necessary, with possible modulations by the plant's N status.

In such conventional agriculture, a great sensitivity to N nutrition takes place early in the cycle, during the florets differentiation (STEER et al., 1984; PALMER and STEER, 1985); more than the leaf area, the N content in leaves and stems can reflect the plant's ability to develop a sufficient number of florets. Then, the reproductive development (bud growth, pollination, achenes setting and filling, especially oil synthesis) is quite dependant on water status, which is well-characterized by the leaf area evolution. It is still not necessary to satisfy the full water requirement of the crop: in this experiment, the maximum yield is obtained with about 550 mm of available water (Table 1), while the maximum evapotranspiration reached 850 mm. Beyond the LAI allowing a correct interception of light energy (about 2.5 to 4) an exess of leaf area increases water requirements without great advantage for yield. Furthermore, a water stress during the vegetative growth induces by a series of physiological reactions a drought adaptation of the plant, which is then able to save water without great damage for yield (BLANCHET et al., 1988; CETIOM, 1990).

Of course, leaves also keep a temporary stock of proteins, which are redistributed to achenes during grain filling (MERRIEN et al., 1988b), and after the florets differentiation the plant N requirements remain rather high, especially to obtain a sufficient quality of meals: Table 1 illustrates this effect of N fertilization. The soil profile and its N residues play there an important role, as demonstrated by VREBALOV et al. (1982) and MERRIEN et al. (1988c). The nitrogen supply must be adapted to the soil and to the expected yield.

In conclusion, water and N are in an intensive agriculture the main factors of sunflower yield, N mainly determining at the early stages the potential number of achenes, and water governing their setting and filling. They both control leaf area, but in the current cropping system the effect of water appears to be quite predominant on LAI and LAD.

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INTERACTIONS EAU-AZOTE LA SURFACE FOLIAIRE ET LES COMPOSANTES DU RENDEMENT DU TOURNESOL.

RÉSUMÉ

L'expansion et la rgression du feuillage du reournesol étant commandées par l'alimentation hydrique et azotée, les interactions eau-N sur l'indice foliaire (LAI), la durée de surface foliaire (LAD), et leurs relations avec les composantes du rendement, sont étudiées dans une expérimentation au champ mettant en jeu différentes profondeurs de sol, fertilisations N, irrigations, et deux cultivars hybrides. Les plantes pouvaient disposer de 100 à 470 Kg $N.ha^{-1}$, et de 200 à 700 mm d'eau; elles étaient indemnes de maladies et de verse. 25 plantes-types par parcelle ont été échantillonnées aux stades étoile, début et fin floraison, ainsi qu'à maturité, pour les mesures de matière sèche et teneur en N des feuilles, tiges et capitules. Les rendements varient d'environ 1.5 à 4.5 $t.ha^{-1}$. L'azote affecte surtout le nombre d'akènes par capitule et leur teneur en protéines; l'eau agit fortement sur le nombre et le poids moyen des akènes, et la teneur en huile. La LAD dépend surtout du régime hydrique, avec une modulation par N. Un LAI d'environ 2.5 suffit à la croissance maximum de l'hybride court, tandis que le plus grand hybride requiert environ 4. A partir de la croissance du bouton floral, le nombre d'akènes est fortement corrélé à la fois à LAI et à la teneur en N des feuilles et tiges. Le poids moyen des akèquent à l'eau disponible. L'azote détermine principalement, aux stades jeunes, le nombre potentiel d'akènes, et l'eau leur nouaison et leur remplissage, avec un effet prédominant sur LAI et LAD.

INTERACCIONES AGUA-NITRťGENO EN EL ŢREA FOLIAR Y LOS COMPONENTES DEL RENDIMIENTO DEL GIRASOL.

RESUMEN

La expansió y la regresión del follaje del girasol siendo regulados por la alimentación hídrica y nitrogenada, las interacciones agua-nitrógeno sobre el índice foliar (LAI) la duración del índice foliar (LAD), y las relaciones con los componentes del rendimiento han sido estudiados a propósito de una experimentación de campo usando distintas profundidades de suelo, distintos niveles de fertilización nitrógenada y de riego y dos variedades híbridas. Las plantas podían disponer de 100 hasta 470 kg $N.ha^{-1}$, y de 200 hasta 700 mm de auga; estaban libres de enfermedades y de encamado. Se le ha puesto anillos a 25 plantas tipos por parcela en la fase de 12 hojas; algunas de ellas fueron seleccionadas a las fases estrella, principio y fin de floración asi que a madurez para medir la materia seca y el contenido en nitrógeno de las hojas, los tallos y las cabezuelas. Los rendimientos varian de aproximadamente 1,5 hasta 4,5 $t.ha^{-1}$. El nitrógeno influye principalmente sobre el número de aquenios por cabezuela y sobre sus contenidos en proteinas; el agua actua sobre el número y el peso promedio de los aquenios y el contenido en aceite. La LAD depende principalmente del régimen hídrico, con una modulación por el nitrógeno. Un LAI de aproximadamente 2,5 es suficiente para el crecimiento máximo del híbrido corto en vez que el grande precisa un LAI de 4. A partir del crecimiento del capullo, el número de aquenios está fuertemente correlado a la vez a LAI y al contenido en nitrógeno de las hojas y de los talos. El peso promedio de los aquenios está fuertemente correlado a LAI a partir de la floración y por lo consecuente al agua disponible. El nitrógeno determina principalmente, durante las fases de juventud, el número potencial de aquenios y el agua su cuajado y su relleno, con un efecto predominante sobre LAI y LAD.