

VARIATIONS OF THE LIGHT EXTINCTION COEFFICIENT AND SUNLIT LEAF AREA IN  
SUNFLOWER AS AFFECTED BY WATER AVAILABILITY.

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SUMMARY

Crop architecture may be altered by water deficit, with changes in the amount of the radiation absorbed per unit leaf area, namely the light extinction coefficient, and in the light distribution within the canopy.

This paper reports on field experiments carried out to assess the effect of variable water availability in modifying the light interception pattern in two sunflower crops. Plants were grown in 1987 and 1990 with two frequency of irrigation: high (HI) and low (LI) frequency. The light extinction coefficient ( $k$ ) and the sunlit leaf area were calculated from light transmission (determined by using line quantum sensors) and LAI.

The LAI was greatly affected by irrigation treatments. In the LI treatment the maximum LAI was 57% and 75% of that recorded in the HI treatment, in 1987 and 1990, respectively.

The light extinction coefficient continuously changed during the crop cycle, following the variations in water availability imposed by the irrigation treatments. In fact,  $k$  increased during some days after an irrigation or a rain. It then decreased until the following rewatering, when the cycle started again. Variations were particularly important in the LI treatment, where the crop experienced extreme changes in water availability. The water related variability of  $k$  caused a concomitant variation in the sunlit leaf area and thus in the light environment inside the canopy, with obvious effects in term of PAR use efficiency and light absorption. Further, results suggest that the dependence of  $k$  on the crop water status is to be considered in models which utilize the LAI to estimate the radiation interception in crops subjected to variable water availability.

INTRODUCTION

In unstressed conditions the biomass yield of a crop is linearly related to the amount of the photosynthetically active radiation (PAR) absorbed during the crop cycle (Hay and Walker 1989, Guiducci, 1988 and 1991; Monteith, 1981). According to Beer's law, PAR absorption depends on the leaf area index and on the light extinction coefficient,  $k$

(Monsi and Saeki, 1953).  $k$  is a function of the characteristics of both the incoming radiation (solar elevation, diffuse over direct radiation, spectral composition, etc.) and the canopy architecture (leaf angle, azimuthal and vertical leaf distribution, optical properties of the leaf, etc.) (Lemeur and Blad, 1974).

Sunflower is typical a planophile plant, i.e. a plant with almost horizontal leaves and consequently it has a high extinction coefficient (Horie and Udagawa, 1971). Moreover, in good growing conditions, light absorption is increased by the diaheliotropic/diahelionastic habit of the plants, which tend to orient their youngest leaves almost perpendicular to the sun rays (Shell et al, 1974; Shell and Lang, 1976). But, in water stressed plants, diahelionastic leaf movements are impossible, due to insufficient leaf turgor. On the contrary, as water deficit increases, leaf wilting promotes parahelionastic movements (Ehleringer and Forseth, 1980), that reduce the light interception, but, according to Lambert cosine law, they also enable the crop to lower the energy load upon the leaf surfaces.

Although parahelionastic leaf movements are well known in many crops in response to water deficit (Berg and Heuchelin, 1990), the influence of the plant water status on the crop architecture needs further study, particularly concerning its direct repercussions on the light distribution inside the canopy.

This paper reports on fields experiments in which the light absorption of sunflower grown with different irrigation levels was measured, to assess the role of leaf movements in the adaptation of the crop to variable water availability.

#### MATERIAL AND METHODS.

*Crop management and treatments.* The experiment was carried out in 1987 and 1990 at the experimental station of the Institute of Agronomy of the University of Perugia (Italy, 43° N. lat, 165 m asl) on a deep clay-loam soil (34% sand, 33% silt, 33% clay). Sunflower was sown on June 19, 1987 and on May 18, 1990, in plots of 10 (1987) or 8 (1990) E-W rows, 8 m long, 0.5 m apart. Just after sowing, 150 kg ha<sup>-1</sup> of N as urea were distributed and the field was irrigated to allow seed germination and emergence. Plant density was adjusted to 6 plants m<sup>-2</sup> by thinning 1 week after emergence, which happened on June 27, 1987 and on June 3, 1990. In a randomized block design with 3 replications, two irrigation treatments were applied: 1) irrigation to restore completely the maximum crop evapotranspiration (HI treatment) and 2) irrigation to restore 1/2 (1987) or 1/3 (1990) maximum crop evapotranspirations (LI treatment). Irrigations were carried out with a constant amount of water (50 mm in 1987 and 40 mm in 1990), whenever the cumulated maximum evapotranspiration corresponded to 50 or 40 mm (HI treatment) and to 100 or 120 mm (LI treatment), in 1987 and 1990, respectively. Daily evapotranspiration was computed from class A evaporation data, corrected with

pan and crop coefficients (Doorembos and Pruitt, 1977).

In both years, rainfall was very scarce and the water table was over 3 m in depth. In the second year, however, due to earlier sowing date, plants experienced better climatic conditions during crop establishment and early growth period.

*Measurements.* The leaf area index (LAI) was determined at weekly intervals by cutting 4 plants per plot excluding border plants, and measuring all the green leaves with an automatic leaf area meter. The flux density of the photosynthetically active radiation transmitted to the soil ( $PPFD_t$ ) was continuously detected by using linear quantum sensors (Guiducci and Cortona, 1987). Sensors were placed in each plot, perpendicular to the crop rows and at the soil level. The irradiance of incoming radiation ( $PPFD_o$ ) was measured by using a LI 190 quantum sensor (Li-Cor, USA) placed at a 2.5 m height. All the sensors were connected to a data logger and  $PPFD$  readings were recorded continuously during the day

Since the light transmission in the canopy is greatly affected by the characteristics of the incoming radiation, only measurements taken at noon on clear days (direct over the total radiation  $> 0.7$ ) were utilized. Only data recorded from about 30 (inflorescence just visible) to 60 (end of flowering) days after emergence (DAE) are reported in this paper. No leaf senescence was observed during that period.

The light extinction coefficient ( $k$ ) was calculated from light transmission and LAI determinations by using the relationship:  $k = -\ln(PPFD_t/PPFD_o)/LAI$  (Lemur and Blad, 1974; Fuchs et al, 1984; Guiducci and Lorenzetti, 1990; Guiducci, 1991). The fraction of the sunlit leaf area (LAIs) was then calculated as:  $LAIs = 1/k (1 - e^{-k LAI})$  (Lemur and Blad, 1974; Horie and Udagawa, 1971).

## RESULTS

Treatments caused important differences in leaf area development. In the HI treatments the LAI was significantly higher than in the LI treatments during the entire period of study (fig 1). The maximum differences were recorded the first year, being in the HI treatment the LAI at flowering 1.8 times higher than in the LI treatment (3.4 vs 1.8). In the second year, in better growing conditions, the LAI was higher in both treatments, at flowering reaching 5.0 in the HI treatment and about 4.0 in the LI treatment.

The estimated extinction coefficient continuously changed during the crop cycle (fig 2).  $k$  increased after an irrigation or a rain, reaching the highest values a few days later. Afterwards, it showed a decreasing trend until the following rewatering, when the cycle started again. The maximum variability in  $k$  was recorded in the LI treatment. In the HI treatment the amplitude of  $k$  changes was less accentuated, but clear at least in the first year. In the well-watered plants before flowering, independent of treatment and year,  $k$  was over 1, i.e. over the maximum theoretical value for plants with horizontal random

distributed leaves, considering the high solar elevation at noon during summer at that location (43° N latitude). This clearly indicates that the young plants had diahelionastic movements that enhanced the light interception by the upper leaf layer. On the contrary, the values recorded for the LI treatment in 1987 and 1990 just before the second re-watering correspond to a mean leaf angle of -65° and -40°, respectively. Thus, it is evident that parahelionastic leaf movements happened as a result of increasing water deficit.

Theoretically, the fraction of sunlit leaf area should decrease continuously during vegetative growth as a consequence of higher mutual shading due to the increasing LAI. On the contrary, in the LI treatment, particularly in the first year, the LAIs/LAI ratio always increased during the second part of the intervals between two consecutive irrigations (fig 3), despite the fact that the total LAI was increasing or constant during those periods. For instance, in a five day period in 1987 (DAE 36 to 41) the sunlit/total LAI ratio increased from 0.48 to 0.70.

## CONCLUSIONS

Leaf movement is a well known characteristic of the sunflower plant (Shell and Lang 1976). Depending on the plant water status, it may serve to either increase or decrease the light interception. Results of this experiment indicate that the leaf angle continuously and reversibly varies, according to the level of available soil water. Namely, in well-watered conditions, the plants have many of their leaf surfaces perpendicular to the sun rays, but as water deficit increases the leaves progressively orient themselves parallel to the sunrays.

Since leaf photosynthesis is greatly reduced at low water potentials (Guiducci, 1992, Connor and Cawood, 1978; Sharp and Boyer, 1986), leaf movement, reducing the energy load, greatly contributes to increasing the water use efficiency (Prichard and Forseth, 1988) and/or to prevent severe and nonreversible damages to the photosynthetic apparatus (Ludlow and Bjorkman, 1984; Hirata et al, 1983). On the contrary, when the water conditions become favourable, stomata open and, the external CO<sub>2</sub> concentration being fairly stable, light becomes the main limiting factor to leaf photosynthesis. Thus the leaves are oriented to receive as much light as possible, considering that at full turgor the sunflower leaf photosynthesis saturates at very high PPF<sub>D</sub> (Louwverson, 1980).

Increase in the sunlit leaf area in stress conditions also means a better light distribution inside the canopy, in the sense that a larger leaf area receives adequate light intensities. In the well-watered crop, instead, the radiation is mostly intercepted by the upper leaf layer and the lower leaves experience very low levels of light intensity. This may explain why the crop radiation use efficiency in these experiments was scarcely sensitive to

water deficit (Guiducci, 1988 and 1991), particularly if compared with the extreme sensitivity of radiation use efficiency observed in the leaves at high irradiance (Guiducci, 1991).

On conclusion, the water-related leaf movement is a crucial phenomenon that allows the plants to control the energy load upon the leaves and the light distribution inside the canopy, in the sense of optimizing the assimilation rate to the actual leaf water status and preventing non-reversible damage to the photosynthetic apparatus.

Finally, the water dependent variations in  $k$  and in the sunlit area are so high that they must be considered in models which utilize the leaf area to estimate the light absorbed by a crop.

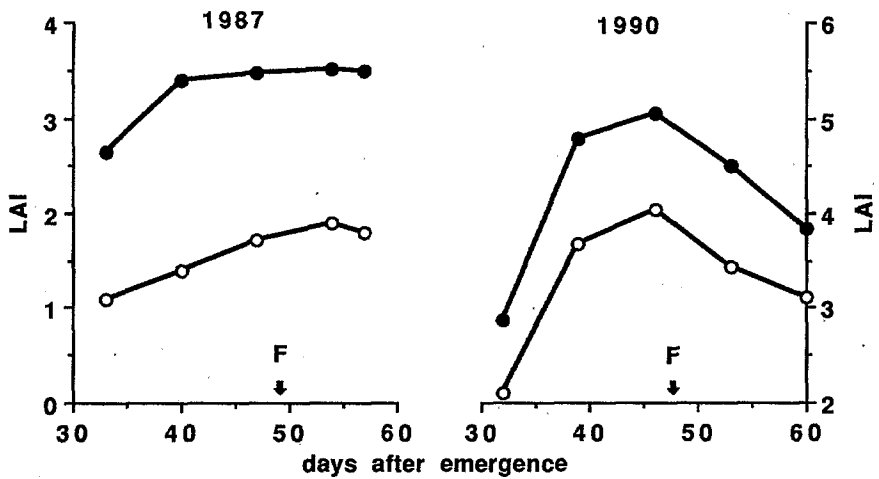


Figure 1 . Leaf area index in sunflower grown with low ( o , LI treatment) and high frequencies of irrigation ( • , HI treatment) .

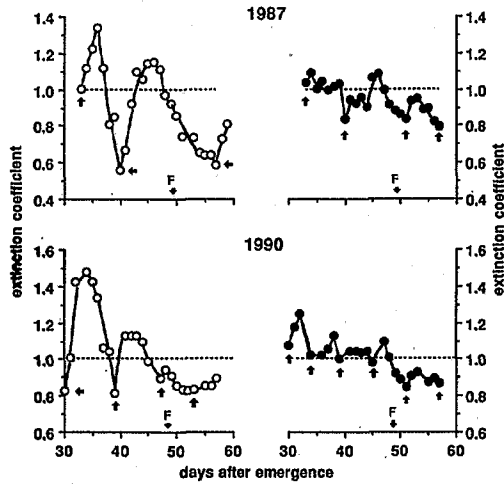


Figure 2. Variations of the estimated light extinction coefficient as affected by irrigation treatments in 1987 (top) and 1990 (bottom). LI treatment (o) ; HI treatment (●). Arrows indicate values recorded the last day before rewatering. F=flowering. Values are relative to determinations performed on clear days at solar noon.

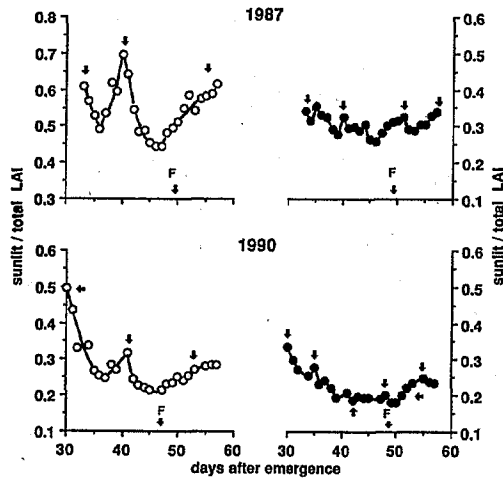


Figure 3. Variations of the sunlit over the total leaf area ratio as affected by irrigation treatments in 1987 (top) and 1990 (bottom). LI treatment (o) ; HI treatment (●). Arrows indicate values recorded the last day before rewatering. F=flowering. Values are relative to determinations performed on clear days at solar noon.

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