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EFFECT OF WATER DEFICIT ON LEAF AREA DEVELOPMENT AND PAR ABSORPTION OF A SUNFLOWER SUMMER CROP.

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SUMMARY

In 1987, a field experiment was carried out in central Italy to study the effect of water deficit on leaf area development and PAR absorption (PARa) of a summer catch crop (sowing, after barley, on June 19) of sunflower (Helianthus annuus L., cv Cerflor, 6 plants m^{-2}).
Just after sowing, the crop was irrigated to allow seed germination and emergence; afterwards three experimental treatments were applied: i) no additional irrigation (control); ii) irrigation to restore half of the crop evapotranspiration (ETc) ($I_{0.5}$ treatment) and iii) irrigation to restore the whole ETc (I treatment).
Treatments showed important differences on plant height and leaf area. At flowering, plant height was 80, 110 and 180 cm and LAI was 0.7, 1.9 and 3.5 m^2 m^{-2}, in the control, $I_{0.5}$ and I treatment, respectively.
From V10 stage to maturity, plants absorbed 33%, 66% and 83% of incident PAR, in the control, $I_{0.5}$ and I treatments, respectively.
Even if PARa was strictly dependent on LAI, a saw-toothed trend was observed in the control and the less irrigated treatment ($I_{0.5}$). In these treatments PARa reached lower values just before an irrigation or rain but it recovered rapidly after water supply.
This seems to indicate that the phenomenon was caused by variations on leaf turgor, due to soil water availability.
In terms of biomass yield, PAR conversion efficiency was higher in the I treatment (0.41 g of d.m. per absorbed E, corresponding to 8.1 kJ E^{-1}) than in the control (0.30 g E^{-1}; 6.4 kJ E^{-1}) and in the $I_{0.5}$ treatment (0.34 g E^{-1}; 7.0 kJ E^{-1}). But in terms of achene yield, differences among treatments were less important and not significant (in average 0.12 g E^{-1}; 3.3 kJ E^{-1}).

RESUME
Effet du déficit hydrique sur le développement de la surface foliaire et sur l' absorption de la radiation photosynthétiquement active (PAR) du tournesol d' été.

En 1987 un essai de champ a été conduit en Italie centrale pour étudier l' effect du déficit hydrique sur le développement de la surface foliaire e sur l' absorption de la radiation photosynthétiquement active (PARa) du turnesol (Helianthus annuus L.) d' été (semé après l' orge, le 19 juin), cv Cerflor a 6 plantes m^{-2}.
Aprés le semis, la culture a été irriguée pour permettre la gérmination des graines et la levee; dès lors trois essais ont été effectués: 1) sans irrigation (contrôle); 2) irrigation pour rétablir la moitié de l' évapotranspiration de la culture (ETc) (traitement $I_{0.5}$); 3) irrigation pour rétablir l' ETc entière (traitement I).
L' essai a démontré des différences importantes pour ce qui concerne la hauteur des plantes et la surface foliaire (ISF). A la floraison la hauteur de la plante était 80, 110 et 180 cm et l' ISF était 0.7, 1.9 et 3.5 m^2m^{-2}, pour le contrôle et les traitements $I_{0.5}$ et I, respectivement.
Du stage V10 (dix feuilles) à la maturité, les plantes absorbaient 33%, 66% et 83% du PAR incident, respectivement dans le contrôle e dans les traitements $I_{0.5}$ et I.
Même si le PARa dépendait strictement du ISF, une tendence irregulière a été observée dans le controle et le traitement $I_{0.5}$. Dans ces essais le PARa a présenté des valeurs inférieures juste avant une irrigation ou une pluie, mais ces valeurs ont rapidement augmenté après l' approvisionnement d' eau. Cela semble indiquer que le phénomène était causé par les changements de la turgescence des feuilles, dû à la disponibilité d' eau dans le sol. En termes de rendement en biomasse, l' efficacité de la conversion du PAR était plus haute dans le traitement I (0.41 g de matière sèche par E absorbé, correspondant à 8.1 kJ E^{-1}) que dans le contrôle (0.30 g E^{-1}; 6.4 kJ E^{-1}) et dans le traitement $I_{0.5}$ (0.34 g E^{-1}; 7.0 kJ E^{-1}). Mais en termes de rendement en grains, les différences entre les essais étaient moins importantes et sans valeur statistique (en moyenne 0.12 g E^{-1}; 3.3 kJ E^{-1}).

INTRODUCTION

In central Italy sunflower is mainly cultivated as a rainfed crop with early spring planting. But when irrigation is possible and early varieties are used, sunflower may also be grown as a summer catch crop, with sowing in late June, just after a winter crop, usually barley, and harvesting in early autumn.

In this case, soil water reserves are very low and vegetative growth occurs during the warmest and driest period of the year. On the contrary, the reproductive phase occurs with lower temperatures and more adequate rainfall. Consequently, water deficit may be very important during the vegetative phase.

Even if sunflower is considered a crop well-adapted to drought, usually it avoids severe water stress in virtue of its earliness and of its capability to deplete water from deeper layers in the soil profile than other crops like soybean (Cox and Joliff, 1987) or sorghum (Bremner et al, 1986). Therefore, if water reserves in the soil are low, sunflower suffers water deficit, which affects leaf expansion rate (Boyer, 1970) and leaf posture and movement (Begg and Turner, 1976) more than leaf emission rate and final number of leaves (Gimenez and Fereres, 1986). Anyway, light absorption is reduced by water deficit (Begg and Turner, 1976), particularly if it happens during vegetative growth. This may explain the correlation between yield and leaf area at anthesis (Rawson and Turner, 1983). However, severe water stress may even reduce leaf photosynthesis, especially through non-stomatal effects (Cox and Joliff, 1987).

Due to lack of data regarding sunflower grown as a summer catch crop, this study was conducted to further examine the effect of water availability on leaf area, light absorption and yield relationships.

MATERIALS AND METHODS

The trial was carried out in 1987 at the experimental station of the Agronomy Institute of the University of Perugia (Central Italy, 42°57' N lat., 180 m a.s.l.) on a deep clay-loam soil with 32.7% (by volume) water content at field capacity and 17.9% at wilting point (-1.5 MPa).

Sunflower (Helianthus annuus L., cv Cerflor) was sown on June 19, just after the harvest of a barley crop. Plots consisted of two subplots with ten East-West rows, 9 m long, 0.5 m apart. Plants were thinned at V2 stage (Schneiter and Miller, 1981) to a population of 6 plants m^{-2}.

Fertilizing was limited to 150 kg ha^{-1} of N, as urea, distributed at sowing. Weed control was obtained mechanically.

Because the soil was very dry, the crop was irrigated (60 mm) just after sowing to allow seed germination and emergence which happened on June 27. Afterwards, three experimental treatments were applied in a randomized complete block design with three replicates: i) no additional irrigation (control); ii) irrigation to restore half of the crop evapotranspiration (ETc) (I$_{0.5}$ treatment), and iii) irrigation to restore the whole ETc (I treatment).

Daily ETc was computed using class A evaporimeter data, corrected by using crop coefficients (Doorembos and Pruitt, 1977). Irrigations, with a constant amount of water (50 mm, corresponding to $2/3$ of the available water in the 0-50 cm soil layer), were executed whenever cumulated Etc
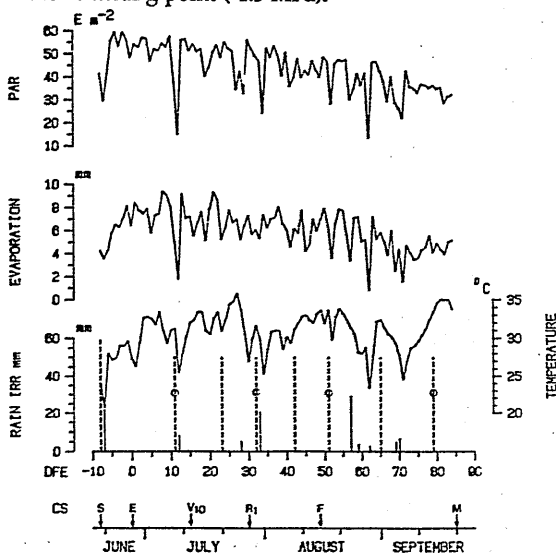

Fig. 1. Daily PAR, pan evaporation, maximum air temperature, rainfall (full bars) and irrigations (dotted bars; circles indicate that only I treatment received irrigation) during the experiment. DFE= days from emergence; CS= crop stage: S=sowing; E=emergence; V10=ten true leaves; R1= visible head; F= beginning of flowering; M= physiological maturity.

corrisponded to 100 mm for I$_{0.5}$ treatment and to 50 mm for I treatment.

I$_{0.5}$ and I treatments received in total 210 and 410 mm of irrigation water, respectively. A drip irrigation system was adopted. During the crop cycle, total rainfall was 102 mm and the water table was always over 3 m in depth. Climatic conditions during the experiment are summarized in fig.1.

From V10 stage to physiological maturity, four plants per subplot were harvested at weekly intervals, excluding border rows and the area of green leaves was measured with an Automatic Area Meter (Hayashi Denko Co, mod AAM-7). During the same period, the interception of Photosynthetically Active Radiation (PAR, $\lambda=400\text{-}700$ nm) by the canopies was determined using 9 original line quantum sensors with 1000x20 mm light sensitive area whose characteristics are reported elsewhere (Guiducci and Cortona, 1987). At the beginning of the measurement period, each sensor was positioned in the center of each subplot, on the soil surface and perpendicular to the rows. Incoming PAR was measured using a LI 190s quantum sensor (Li-Cor, Nebraska, USA) placed in the center of the field at a 2.5 m height. All sensors and a wet-dry bulb psycrometer were connected with a CR7 datalogger (Campbell inc., Utah, U.S.A.).

Daily, from sunrise to sunset and for the entire measurement period, light and temperature readings were executed automatically every 3 minutes and integrated values of PAR and maximum air temperatures were recorded. Albedo in the visible region was considered constant throughout the field.

Achene yield was determined by harvesting manually six rows of each plot. Above-ground biomass was obtained by weighing the vegetative parts of the harvested area and sub-sampling for moisture content. The energy content of the dry matter of achenes and vegetative organs was then determined using an O_2 calorimeter (IKA-Kalorimeter, mod C 400, Germany).

A sample of 300 seeds was counted and weighed (after drying) to compute single seed weight. Number of achenes m^{-2} was then calculated using seed weight, heads m^{-2} and achene yield.

RESULTS

Biomass and achene yield. Above-ground biomass and dry matter (d.m.) distribution within plants were greatly affected by treatments (tab.1).

Reduced water availability caused a significant decrease of biomass yield (BY) and it enhanced harvest index (HI). So achene yield (AY) was proportionally less affected by treatments than BY. Irrigation equally improved achene m^{-2} number and achene weight (tab.1).

Energy content of d.m.. The energy content (EC) of plant d.m. was significantly lower in the I treatment than in other treatments. However, both the EC of achenes and vegetative organs were unaffected by water availability (tab.1), so the differences in EC of plant d.m. reflect the change in HI.

Tab. 1 .Effect of treatments on dry matter production, harvest index, yield components and energy content of dry matter. Weights are on dry basis.

	Biomass yield g m^{-2}	Achene yield g m^{-2}	Harvest index %	Achene weight mg	Achenes m^{-2} n.	Energy on d.m. plant kJ g^{-1}	achenes kJ g^{-1}	veg. parts kJ g^{-1}
Control	288 c	107 c	37 a	23.9 c	4362 c	21.1 a	28.8 a	16.5 a
$I_{0.5}$ treatment	633 b	228 b	36 a	34.6 b	6582 b	20.7 a	28.5 a	16.1 a
I treatment	972 a	279 a	29 b	38.6 a	7228 a	19.6 b	28.8 a	16.3 a

Means followed by same letters are not significantly different at P≤ 0.05.

Canopy and leaf area development. The growth of plants was rapid: flowering happened on day 48 from emergence (DFE) and physiological maturity 36 days later, regardless of treatment.

Irrigation caused significant differences in plant height, head diameter, maximum leaf area index (LAI) and leaf area duration (LAD) (tab. 2). Neither leaf appearance rate nor maximum number of leaves were affected by water availability.

In I treatment LAI increased rapidly during the vegetative stage. Maximum LAI was recorded on DFE 40 and LAI began to drop about 3 weeks later.

LAI increased more slowly and its maximum value was achieved later in $I_{0.5}$ treatment than in I treatment, while the LAI of control plants stopped rising very early during the vegetative phase (fig. 2a). Notwithstanding the great differences in maximum LAI, there was no effect due to treatments on time of complete plant senescence (fig. 2a)

PAR absorption (PARa). Fig. 2b reports daily PARa (in percent of incident radiation) from V10 stage to maturity.

In I treatment, PARa increased during the vegetative stage to over 95%, which was achieved about 2 weeks before flowering. In the other treatments, a saw-thooted trend of PARa was observed: PARa

reached lower values just before an irrigation or rain (see arrows in fig. 2b) but it recovered rapidly after water supply. Although less evident, such a pattern was observed in I treatment, too.

Tab. 2. Effect of treatments on some morphological characters.

	Head diam. cm	Plant height cm	maximum LAI $m^2 m^{-2}$	LAD $m^2 m^{-2} d$
Control	11.3 b	80 c	0.7 c	41 c
$I_{0.5}$ treatment	13.2 ab	110 b	1.9 b	86 b
I treatment	15.1 a	180 a	3.5 a	170 a

Means followed by same letters are not significantly different at P≤ 0.05.

In the control PARa increased from DFE 34 to DFE 70 when the period of fast plant senescence began.

From V10 stage to maturity, the most irrigated plants (I treatment) absorbed 2358 E m^{-2} corresponding to 83% of the incident radiation. Reduced water availability caused a significant decrease on PARa, which ranged from 925 E m^{-2} (33%) in the control to 1852 E m^{-2} (66%) in $I_{0.5}$ treatment (tab. 3).

In terms of biomass yield, the efficiency of plants to convert absorbed radiation (PARe) to d.m. or energy was significantly improved by irrigation, but the differences in PARe were less accentuated on energy than on d.m. basis. In terms of achene yield, differences on efficiency were lower and not significant (tab. 3).

DISCUSSION

Results of this field experiment clearly indicate that PAR absorption is strongly affected by water availability.

The differences among treatments on PARa were strictly dependent on the effect of water availability on LAI and LAD. In fact, using single plot data, PARa [E m^2] was related to LAD [$m^2 m^{-2}d$] by a log relationship (PARa= 942 $\log_e$(LAD)-2444; n=9; r=0.98 **).

However, daily PARa changes were frequently opposite of LAI changes, particularly in the control and $I_{0.5}$ treatment (fig. 2a and 2b).
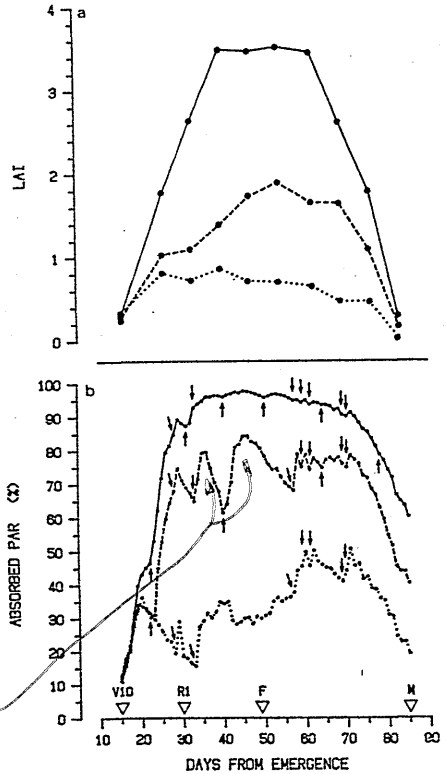

Fig 2. Effect of treatments on (a) LAI and (b) daily PARa (in percent of incident radiation). (———) = I treatment; (-----) = $I_{0.5}$ treatment; (········) = control.
↑ and ↓ represent irrigations and rains, respectively.
See fig. 1 for crop stage symbols.

This suggests that the efficiency of leaves to intercept light per unit of LAI, namely the extinction coefficient (k) (Monsi and Saeki, 1953), was continuously changing during the crop cycle.

Tab. 3. Photosynthetically active radiation (PAR) absorbed by plants from V10 stage to maturity and efficiency of PAR conversion to dry matter and energy.

	PAR absorption E m^{-2}	% *	PAR conversion efficiency biomass g E^{-1}	kJ E^{-1}	achenes g E^{-1}	kJ E^{-1}
Control	925 c	33	0.30 b	6.4 b	0.12 a	3.2 a
$I_{0.5}$ treatment	1852 b	66	0.34 b	7.0 b	0.12 a	3.3 a
I treatment	2358 a	83	0.41 a	8.1 a	0.12 a	3.5 a

Means followed by same letters are not significantly different at P≤0.05.
(*) With respect to incident radiation (2840 E m^{-2})

Because PARa decreased before a irrigation or rain and it recovered rapidly after water supply, the changes in k reflect variations in plant water status, due to soil water availability. As known, during short periods (i.e. with limited variations on solar declination) k depends on leaf angle (Lemeur,1973) which is particularly affected by wilting. Further, the typical heliotropic movement of sunflower leaves (Shell et al, 1974) is reduced or impossible in wilted leaves.

The increasing trend of PARa observed in the control from DFE 34 to DFE 70 probably is due to decrease on

solar declination (from about 18° 30' to 7°), with consequent increase both in k and in light interception by stems and heads. Of course, this is true for all treatments but it became evident only in the control, because of lower LAI values.

Many authors report linear or log relationships between light absorption and biomass production (Fasheun and Dennett, 1982; Rawson *et al*, 1984). Here, better correlation is achieved by exponential relation (BY [g m^2]= 112 e $^{9.3 \cdot 10^{-4}}$ PARa; n=9; R^2=0.96). However, when BY was expressed on an energy basis (BYe), the highest correlation was given by a linear relation (BYe [kJ m^2]= 8.9 PARa - 2490; n=9; r=0.99**).

Anyway, water stress was so severe causing a reduction in both the dry matter and the energy produced by plants per quantum of absorbed radiation (PARe , tab.2).

However, due to effect of water stress on d.m. and energy partitioning within the plant (tab. 1), in terms of conversion yield (d.m. or energy) PARe was unaffected by treatments and achene yield was linearly related to PARa (AY [g m^2] = 0.124 PARa-8.52; n=9; r=0.99** and AYe [kJ m^2]= 3.5 PARa-114.5; n=9; r=0.99**).

The drop in HI in I treatment disagrees with data of Gimenez and Ferreres (1986) who reported lower indices on water stressed plant .

Undoubtedly, the high HI of the control and I$_{0.5}$ treatment reflects the particular environmental conditions that a summer crop encounter. It is important to note that, in this experiment the first important rain (20 mm) fell only 34 days after emergence, i.e. with plants at the beginning of the phase of intense head growth (R1 stage, fig.1). Thus, water availability was greater during head growth than during the previous period. As a consequence, treatments affected more plant height (i.e. stem weight) than head diameter, achenes m^{-2} and achene weight (tab.1), causing the increase on HI.

CONCLUSIONS

Results of this preliminary study permit the following conclusion to be drawn:

i) Light absorption by plants is extremely sensitive to variation in plant water status, which affects both the leaf area development and the efficiency of leaves to absorb light.

ii) Changes in the extinction coefficient (*k*) are so wide that they are to be considered when PARa is used to model plant growth or canopy photosynthesis of sunflower, particularly if soil water availability changes irregularly.

iii) Because even a single rain my assume a great importance in plant growth and in central Italy rainfall is very scarce and irregular during summer months, further experiments are needed to fully test the performance of summer sown sunflower.

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