Seed Population Density Correlates Well with the Photothermal Quotient in Sunflower (*Helianthus annuus* L.)

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Abstract

A simple quotient (photothermal quotient, **[PQ= mean radiation/(mean temperature-base temperature)]**) has been shown to capture the effects of radiation and temperature on the number of seeds m^{-2} (NS) in unstressed crops of several species. The objective of our experiments was to determine whether **PQ** is a good predictor of NS in sunflower.

Crops of Prosol 35 (PRODUSEM) were grown in different conditions of radiation (range 14 to 24 MJ.m $^{-2}$ d^{-1}) and temperature (20°C to 24°C) using inter and intra-annual variations in sowing dates and artificial shading (temperature/radiation combinations=18). **PQ** was calculated for the period 30 days before to 20 days after anthesis, the ontogenic phase during which NS is fixed in sunflower (determined in other experiment). Base temperature (Tb) used was 4°C.

The results showed a significant ($p<0.00001$) relationship between NS and incident short-wave radiation ($r=0.81$) during this period and a poorer correlation with temperature ($r=-0.54$; $p<0.05$). The correlation ($r=0.84$; $p<0.000001$) between NS and **PQ** was better than that achieved by either variable alone. We conclude that **PQ** would be a better tool to predict NS in sunflower crop models than the use of radiation alone.

Keywords: sunflower; seed number m^{-2}; photothermal quotient; temperature; radiation.

Introduction

The potential yield in several crop species (wheat, maize, sorghum, rice) is affected by radiation and temperature when they are grown under adequate levels of nutrients, water supply and in the absence of pests and diseases. Both variables affect the crop growth and development, modifying the potential number of seeds m^{-2} (NS). The number of flowers is related with the differentiation rate of florets, and specially with the duration of the period in which this process occurs. When the temperature rises the differentiation rate increases, but the period in which the florets differentiate and grow is reduced. The temperature effect on the duration of the period is higher than on the differentiation rate, resulting in a reduction of NS at high mean temperatures. In the same way, when the mean temperature rises the chronological time for seed setting is reduced, and so is the amount of intercepted short-wave radiation for unit of time of seed development (Nix, 1976, Rawson, 1990).

NS is affected by to the radiation intercepted by the crop during a window of time which varies between species. Using artificial shading Chimenti and Hall (1992) found that this window for sunflower is between 16 days before and the 20 days after 50% anthesis. In another experiment (Chimenti *et al.*, unpublished) the results suggest that the window begins at floral initiation (approximately the 30 days before anthesis).

A simple quotient has been shown to capture the effects of radiation and temperature on the NS when applied over the appropriate window of time for each species (Nix, 1976). This quotient, termed phototermal quotient (PQ= mean R/(mean temperature-base temperature)), has been used in different crops to predict NS with good results (Fischer, 1985, Rawson, 1987, Andrade *et al.*, 1992, Islam and Morison, 1992, Ortiz-Monasterio R., 1994). The objective of our experiments was to determine whether PQ is a good predictor of NS in unstressed sunflower crops.

Materials and Methods

Two experiments were conduced in the experimental field of the Facultad de Agronomía, Universidad de Buenos Aires (34° 35'S 58° 29' W). Crops of sunflower (cv. Prosol 35, Produsem) were grown under field conditions with good water and nutrition availability. Plant density was 5.1 plants m^{-2} (0.70 m * 0.28 m). Crops were kept free from weeds, insects and diseases.

Experiment 1

This experiment was conducted with the goal of having a wide range of mean daily short-wave radiation during the 30 days before and the 20 days after 50% of anthesis (critical period, CP). Crops were exposed to a high (80%) or low (50%) shading treatments during 10 day intervals at different times during the CP (Fig.1). The low level shading had 3 additional 20 day-treatments. Figure 1 shows the distribution of the 8 treatments of light shading (5 of 10 and 3 of 20 days duration) and 5 treatments of heavy shading (10 days) during the CP.

The dimension of the shaded plot (experimental unit) was 3 rows * 1.7 m. The height of the structure used to support the shade-cloth was graduated as required to follow the growth of the crop. In each experimental unit 4 heads were harvested from the central plants of the central row of the plot. The mean number of seeds from those 4 heads was considered a replication. The number of replications for each treatment was 3. All heads were harvested at physiological maturity.

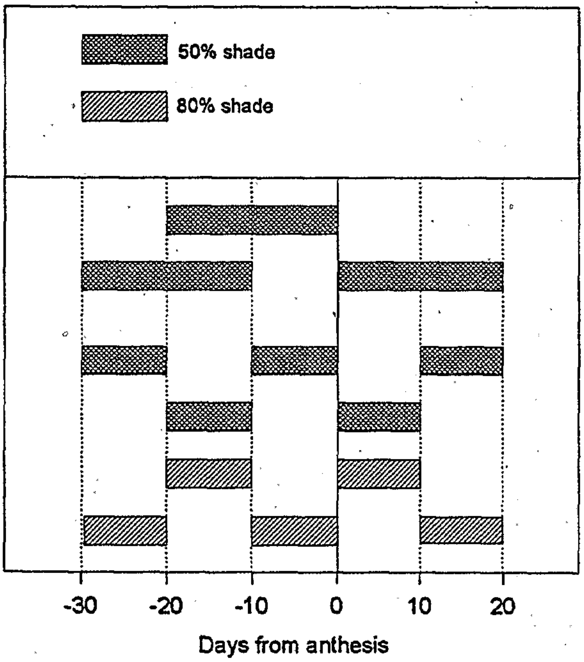

Figure 1. Shading chronogram. Horizontal bars represent the duration of the shading period.

Experiment 2

Three consecutive sowings were carried out during one year with the objective of obtaining different combinations of radiation and temperature (i.e. PQ) during the critical period.. Anthesis dates were 01/18/94 (sowing 1), 11/07/94 (sowing 2) and 12/02/94 (sowing 3). The dimension of each experimental unit (3 for each sowing date) was 7.0m (9 rows) by 8.4m (30 plants in the row). Five randomized plants were harvested in each experimental unit. The mean of the 5 plants was a replication.

In the two experiments, daily incident short-wave radiation (R) and daily mean temperature (Td) were recorded by an automatic weather station (21X micrologger, Campbell Scientific, Logan, Utah, USA). Measurements of fractional radiation interception (Qm) by the canopy were taken twice weekly.at noon Qm was transformed into daily fractional interception (Qd) using the equation of Orgaz *et al.* (1992). Fitted functions relating Qd to time were used to transform R into mean daily intercepted short-wave during the CP (R_{im}). The mean temperature of the CP (Tm) was calculated using the daily mean temperature. PQ was calculated as PQ=

[R_{im}/(Tm-Tb)], where the base temperature (Tb) used was 4°C (Villalobos and Ritchie, 1992).

Linear regression models (Netter y Wasserman, 1984) were used to define the association between variables, and the stepwise multiple correlation method for independent variable selection (Kleinbaum and Kupper, 1978) was used to establish the statistical model which best explained the variance of NS as a function of combinations of independent variables.

Results

R_{im} explained a 65% of the variability in NS ($p<0.00001$; $r=0.81$; $n=52$, Fig. 2a, values shown in brackets indicate levels of significance for intercept and slope in reference to 0)

$$NS = -1239\ (ns) + 533\ (p<0.00001)\ R_{im} \qquad \text{(eq. 1)}$$

A simple analysis of the relationship between NS and [Tm-Tb] using all data point was inappropriate because the shading treatments were the source of most variability in NS (filled symbols, Fig. 2b). When the analysis was confined to the treatments in which there was not artificial shading (open symbols, Fig. 2b), this showed a reduction in NS as [Tm-Tb] rose, explaining the 29% of the variation of NS (r -0.54; $p<0.05$; $n=17$)

$$NS = 16848\ (p<0.0001) - 409\ (p<0.05)\ [Tm-Tb] \qquad \text{(eq.2)}$$

When the two variables (R_{im}, [Tm-Tb]) were combined in PQ (Fig. 2c) the correlation coefficient between NS and PQ was significantly better than that achieved by either variable alone ($p<0.000001$; $r=0.86$; $n=52$; combination R_{im}/[Tm-Tb]=18; equation 3), explaining the 73% of the variation in NS.

$$NS = -436\ (ns) + 9214\ (p<0.000001)\ PQ \qquad \text{(eq.3)}$$

When stepwise multiple correlation for independent variable selection was used to evaluate relationships between NS and combinations of independent variables (99% significance level to exclude or include a variable), the ranking of the models was: 1st PQ alone (eq. 3), next the multiple regression ($r= 0.84$; $n=52$):

$$NS = 11588\ (p<0.005) + 465\ (p<0.00001)\ R_{im} - 611\ (p<0.0005)\ [Tm-Tb] \qquad \text{(eq. 4),}$$

followed by eq. 1, and finally eq. 2.

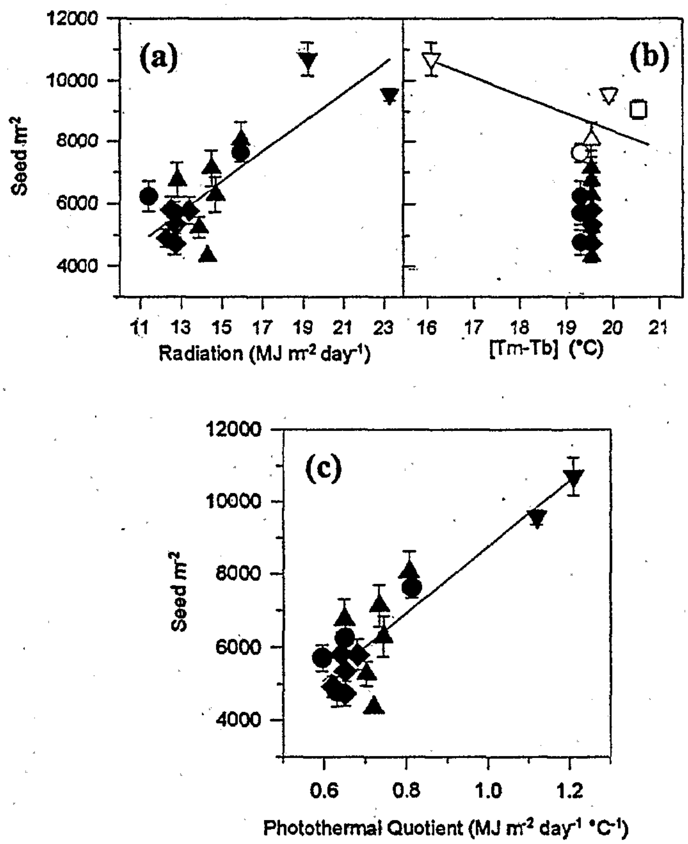

Figure 2. Relationships between NS and the independent variables: mean radiation (a) [n=52; eq.1]; mean temperature-base temperature (b) [n=17; eq. 2]; phototermal quotient (c) [n=52; eq.3]. Symbols: year 1993/94: (●), 20 days shading; (▲), 10 days shading at 50% interception; (◆), 80% interception; year 1994/95: (▼), successive sowings. In b, the regression line was calculated only with the unshaded treatments, identified (this figure only) with open symbols (see text). (□), Chimenti *et al.* (1991/92) (unpublished). In the three figures data points shown are means± standard errors for each treatment.

Discussion

When Tm and R_{im} were combined in PQ the correlation with NS was significantly better than both [Tm-Tb] and R alone, so the sunflower has, in that sense, a similar response that observed in other species. In wheat, a higher degree of association between NS and Tm was found (Fischer, 1985). In our work the [Tm-Tb] explains only the 29% of the variability in NS. The cause could be the narrow range of Tm obtained by successive sowings in a year and the variation among years. The range in this work was 4°C (16-20°C), less than the half of the 8.4°C explored in wheat (Fischer, 1985). In spite of the relative poor association between NS and Tm, its effects (when both R_{im} and [Tm-Tb],were combined in PQ) were enough to significantly improve the correlation in comparison with the use of the radiation alone.

The association found between NS and PQ should be important for the sunflower crop models (e.g. Villalobos *et al.*, 1992). In the current models the mean photosynthesis in a fixed period is used to predict NS. The temperature effect in the duration of CP is not assumed. The PQ in this work also has a fixed CP but, with the Tm in the denominator, changes in the calendar length of the CP are partly accounted for. The ontogenic routine of the crop models can calculate the floral initiation date, the anthesis date and the beginning of seed filling date. The CP runs approximately between floral initiation and the beginning of seed filling, so, a strong association between NS and PQ suggest that the intercepted radiation accumulated during this ontogenic period would provide a better estimate of NS.

Conclusion

This work shows a strong relationship between NS and PQ in sunflower, more important than the relationship between NS and R_{im} or Tm alone. Future research that will complement this work should include:

a) the temperature and radiation effects on seed weight;

b) the effects of suboptimal temperatures for photosynthesis and the supraoptimal temperatures for development on the NS/PQ relationship.

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