The temperature regime of the sunflower capitulum: an energy balance model.

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Abstract

A model for predicting the dynamics of both grain and receptacle temperatures has been formulated and tested. Required inputs are half-hourly values of air temperature, humidity and radiation; and the model produces estimates of grain and receptacle temperatures. The model simulates shortwave irradiation absorption, net longwave and latent heat exchange, convection, conduction, and heat storage; and accounts for effects of capitulum position (vertical position, with heads directly exposed to the solar radiation; or horizontal position, with heads hidden within the upper layers of the canopy and remaining partially shaded). The model accurately predicts grain and receptacle temperatures for vertical and horizontal heads, on both sunny days and cloudy days (r^2=0.95-0.98, predicted vs. observed values, 15-38°C temperature range). Since the thermal regime of the grain affects the duration of grain filling, this model is a good tool for exploring the likely effects of capitulum position and site-dependent differences in radiation and temperature regimes on the duration of grain filling, and hence, yield.

Keywords: capitulum, sunflower, *Helianthus annuus* L., temperature, radiation interception, energy balance.

Introduction

Grain temperatures for sunflower plants with heads in the vertical position during the whole of the grain filling period can be up to 10°C higher than air temperature and have a higher daytime thermal regime than plants with their head hidden within the upper layers of the canopy that remain partly shaded during the post-anthesis period (Ploschuk and Hall, 1995). The higher temperatures in vertical heads reduce grain-filling duration and grain yield. However, radiation intercepted by the head could be expected to vary between sites and years, and little is known about the relative disadvantages of cultivars with vertical heads for areas with different radiation regimes. In order to explore the possibly effects of capitulum position and radiation regime on the thermal regime of the head, a simulation model for predicting the dynamics of both grain and receptacle temperatures has been formulated and tested. This model utilizes as inputs half-hourly values of air temperature, humidity and radiation, recognizes if the sky is clear or cloudy, and produces estimates of grain and receptacle temperatures.

Materials and methods

The model is formulated in BASIC, and its general structure is based on the energy balance reported by Lewis and Nobel (1977) for *Ferocactus acanthodes*. The following equation shows the six heat transfer and storage processes simulated for the energy balance of sunflower capitula.

$$Ra+Re+Cv+Cd+Lh+Hs=0$$

where Ra= absorbed shortwave irradiation, Re= net longwave exchange, Cv= convection exchange, Cd= conduction exchange, Lh= latent heat exchange and Hs= heat storage. Derivation of each term is explained below.

$$Ra=a\ (Rdir + Rdiff)$$

where "a" is the shortwave absorptance, measured experimentally (0.73 and 0.78 for grains and receptacle respectively); and is assumed to be the same for both direct (Rdir) and diffuse (Rdiff) radiation. It is assumed that head is oriented with the grains 105° to east respect to north (South hemisphere). For sunny days, in vertical heads, daily Rdir/time relationship was estimated for both grains and receptacle, based on equations reported by Loomis and Connor (1992) and angular transformations given by Sellers (1965). Rdiff is assumed as spatially directional on clear days, with a maximum assigned value of 0.1 kW m^{-2} (Sinclair et al., 1992). For cloudy days, it is assumed that all radiation is diffuse, with an uniform spatial distribution pattern (Uniform Overcast Sky, UOC, Monteith, 1973). In horizontal heads, both on sunny and cloudy days, radiation incident on the head is estimated as:

$$I=I_0\ e^{-kL} \text{ (Charles Edwards, 1986)}$$

where I is the radiation received by the organ, L is the leaf area interposed between incident radiation (I_0) and the organ, and k is the extinction coefficient of the canopy (0.7, Sadras et al., 1991).

$$Re=e\ \sigma\ (T^4env-T^4\ surface)$$

where "e" is the longwave emittance coefficient, estimated as 0.95 (Monteith, 1973), σ is the Stefan-Boltzmann constant, and T env is the temperature of the environment facing the organ. In vertical heads and horizontal grains, daily measured Tenv were roughly equal to T air, so it is assumed that T env=T air. In horizontal grains, Tenv was estimated as (T air - 2) during the night, assuming that ground temperatures were cooler than air values during this period. In horizontal receptacles, it is assumed that Tenv=(T air - 4) during the 24h because this organs were partially exposed to the sky.

Convection (h_c), conduction (K), conductance (G_{wv}) and heat storage (C_p)

coefficients were estimated by analyses of observed grain and receptacle temperatures (Ploschuk and Hall, 1995), during appropriate periods of the day.

$$Cv=h_c\ (T\ air\text{-}T\ surface)$$

where estimated h_c was 0.015 kW m^{-2} K^{-1}, a value similar to that obtained by Lewis and Nobel (1977) in cactus for a wind speed of 10 km h^{-1}.

$$Cd=K\ dT/dx$$

where estimated K was 0.0003 kW m^{-1} °K^{-1}, similar to that reported by Jones (1986) for leaves. dT/dx is the temperature gradient between receptacle and grains.

$$Lh=L\ G_{wv}\ dC_{wv}$$

where L is the latent heat of vaporization of water, and dC_{wv} is the deficit of the air saturation. It is assumed that G_{wv} is zero in grains. In receptacle, it is assumed that G_{wv} is zero during the night, while daytime values were estimated as 0.0025 m s^{-1} when is shaded and 0.007 m s^{-1} when solar radiation impinged directly.

$$Hs=C_p\ V\ dT/dt$$

where estimated C_p was 0.002 and 0.001 kJ cm^{-3} °K^{-1} for grains and receptacle respectively, similar to those reported by Jones (1986) for leaves. V is the organ volume and dT/dt is the temperature change per unit time.

The accuracy of the model was tested by estimations of mean absolute errors (MAE, Mayer and Butler, 1993) as

$$MAE=(\sum|observed\ temp - predicted\ temp|)/n$$

Results and Discussion

When the model was tested with data not used for the formulation of the model, daily grain and receptacle temperature/time relationships for both vertical and horizontal heads were reasonably well predicted for sunny days (Fig. 1) and cloudy days (data not shown). A good association between observed vs. estimated values for both grains and receptacle was found in both vertical and horizontal heads (Fig.2), although the model showed a slight tendency to overestimate high temperatures on horizontal heads. The variability in the leaf area interposed between incident radiation and the horizontal receptacles, and the lack of more accurate estimations of Tenv values are two possible causes of this bias. Significant differences ($P<0.05$) were found for slopes respect the 1:1 relationship, excepting the receptacle for vertical heads. Intercepts did not differ significantly from 0 in any case. Over a 15-38°C temperature range, MAE were only between 0.7-0.9°C, indicating a good accuracy of the model for predicting both grain and receptacle temperatures over the expected range of temperatures.

In its present form, this model is a good tool for exploring the likely effects of capitulum position and site-dependent differences in radiation and temperature regimes on the duration of grain filling, and hence, yield.

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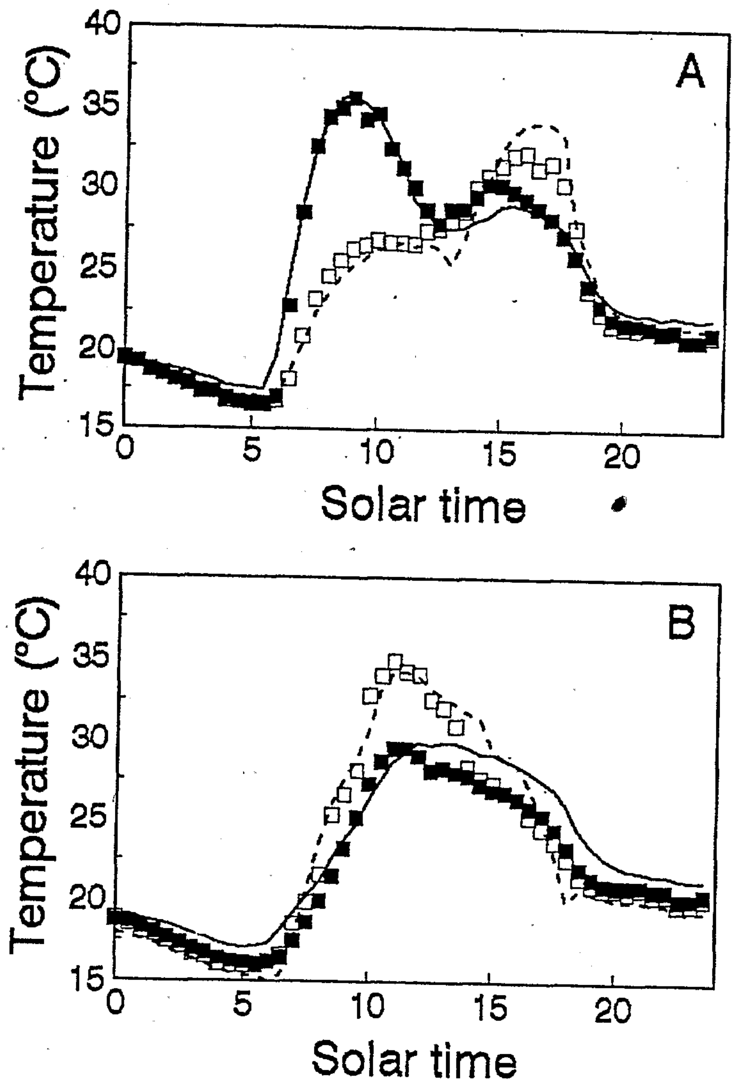

FIGURE 1. Daily temperature/time relationship predictions for vertical (A) and horizontal (B) heads. Symbols and lines indicate observed and predicted values respectively for grains (■,—) and receptacle (□,- -).

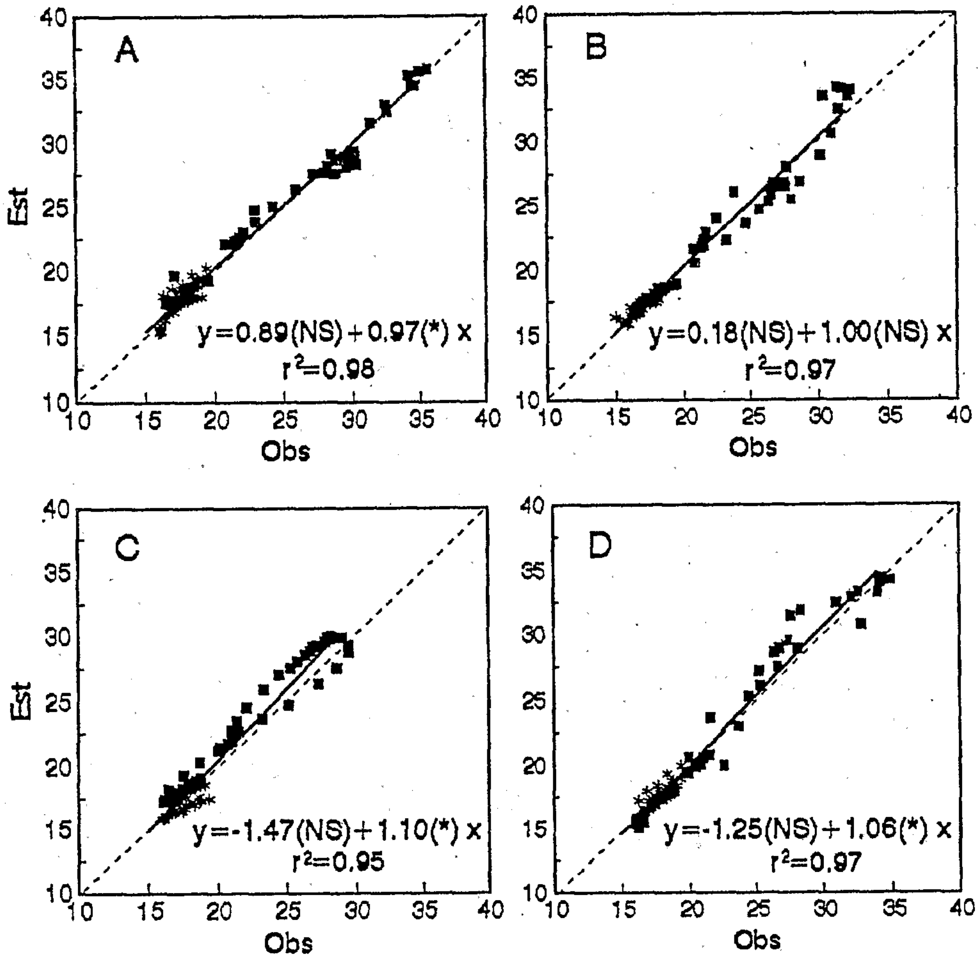

FIGURE 2. Estimated vs. observed temperatures for grains (A,C) and receptacle (B,D), on vertical (A,B) and horizontal (C,D) heads. Data were obtained on sunny (■) and cloudy (✱) days. Dashed lines show the 1:1 relationship.
NS=non significant *=P<0.05