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A COMBINATION OF MECHANISTIC AND EMPIRICAL MODELS TO PREDICT GROWTH AND YIELD OF SUNFLOWER AS INFLUENCED BY IRRIGATION AND MOISTURE STRESS

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SUMMARY

Sunflower (*Helianthus annuus* L.) is an important oil seed crop grown quite often in drylands. The variability in rainfall occurrence in these regions makes crop production risk and the crop experiences moisture stress at different growth stages. Crop simulation models help to assess such production risks. This paper described the development and testing of a combination of mechanistic and empirical models of sunflower. The model uses a few conservative relationships to define leaf area development as a function of leaf number and in turn leaf number as a function of accumulated thermal units. Biomass accumulation was simulated as a function of fraction of photosynthetically active radiation interception and radiation use efficiency. Seed growth was simulated from linear increase in harvest index with time. The model was calibrated empirically to predict the growth and yield of sunflower as influenced by irrigation and moisture stress effects by developing suitable sensitive factors. The model performed satisfactorily in predicting the aboveground biomass, leaf area and final yield of sunflower as influenced by irrigation and moisture stress.

Key words: **sunflower, simulation, mechanistic model, irrigation, moisture stress**

INTRODUCTION

Sunflower is an important oil seed crop which is quite often grown in dryland conditions. Hence, the crop experiences moisture stress at different pheno-phases during its growth. Quantification of the effect of moisture stress and effect of irrigation on growth and yield of sunflower is important in selecting this crop for differ-

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ent agro-climatic situations (Sridhara, 1977). Lately, crop simulation models have been developed to predict the growth and yield of different crops under different sets of agro-climatic situations. These models also serve as a management decision tools (Boote *et al.*, 1985; Menike *et al.*, 1993; Sandras and Villalobes, 1994).

Several simulation models have been developed for the sunflower (Horie, 1977; Anderson *et al.*, 1978; Steer *et al.*, 1993; Chapman *et al.*, 1993). The above models describe plant processes at various degrees of complexity which need to be calibrated before testing in other countries. Hence, an attempt was made here to develop and evaluate a site- and cultivar-specific combination model based on relatively few conservative relationships developed from mechanistic and empirical perspectives (Sinclair, 1986; Amir and Sinclair, 1991) with a daily time step that simulates the response of sunflower to irrigation and moisture stress.

MATERIALS AND METHODS

Two field experiments were conducted to develop and evaluate a simulation model to predict the growth and yield of sunflower as influenced by irrigation regimes and moisture stress experienced by the crop at different growth stages.

Experiment 1

A field experiment was conducted during the summer season of 1994 at Gandhi Krishi Vignyna Kendra, University of Agricultural Sciences, Bangalore. The soil was a sandy loam of medium fertility with pH of 5.60. The soil contained about 189.0 kg ha^{-1} of available N, 18.3 kg ha^{-1} of Bray's P_2O_5 and 224.0 kg ha^{-1} of exchangeable K_2O. The treatments included were four irrigation regimes viz., weekly irrigations given at 0.4, 0.6, 0.8 and 1.0 cumulative pan evaporation (CPE). The measured quantities of water were applied by flooding once every seven days. The experiment was laid out as randomized block design with four replicates. The sunflower cv. KBSH-1 was sown following a spacing of 60 x 30 cm and the conventional cultivation practices were followed.

Experment 2

This field experiment was conducted during the summer season of 1995 at the same site and location. The treatments included were three irrigation regimes viz., weekly irrigation given at 0.4, 0.6 and 0.8 CPE and the moisture stress treatments included were normal irrigation (no stress), moisture stress during primordia initiation (20-35 DAS), budding (35-50 DAS), flowering (50-65 DAS) and seed filling (65-80 DAS). These treatment combinations were laid out in a factorial randomized block design with three replicates. Moisture stress was imposed by withholding water for fifteen days during respective growth stages. The other details with respect to the soil, cultivar and cultivation practices were similar to experiment 1.

Collection of data

Daily minimum and maximum temperature, rainfall, class A pan evaporation were recorded at the experimental station. The amount of solar radiation was calculated by following an Angstrom subroutine of the ORYZA model described by Drenth *et al.* (1994). The data on leaf number, leaf area and total biomass were recorded at fifteen-day intervals starting from 15 DAS in both experiments. The leaf area was measured by using leaf area meter (LICOR-3000).

The data on seed weight per plant were recorded once every seven days from the onset of anthesis till maturity in experiment 1.

Model description

The combination model was developed based on relatively few conservative relationships developed from the mechanistic perspective (Sinclair, 1986; Amir and Sinclair, 1991). It involved four modules viz., simulation of leaf area, biomass accumulation, seed growth and calibration. The model was first developed by using the data from the treatment that received irrigation amounting to 1.0 CPE, to predict the potential yields of sunflower under optimum conditions (resource adequate). Then the model was calibrated empirically to predict growth and yield of sunflower as influenced by irrigation and moisture stress.

Ontogeny

Crop ontogeny was divided into two phases viz., vegetative and seed growth period. Each ontogenetic period was well defined by the accumulated thermal units (TUs, °C) experienced by the crop in each period. Daily TU was calculated as an average of the minimum and maximum temperature minus a base temperature. The base temperature for the sunflower was found to be 8.5°C as suggested by Sadras and Hall (1988). The crop took 1420 TUs to reach maturity. The duration of seed growth was set to begin at 660 TUs in all simulations (Shridbara, 1997).

Simulation of leaf area

Leaf area on any day is a function of leaves per plant and area of individual leaves. Leaf production and expansion rate in sunflower is largely influenced by temperature and it depends on accumulated TUs (Muchow and Craberry, 1989; Chapman *et al.*, 1993). On any day leaf area was determined as a simple quadratic function (Figure 1) fitted between leaf area (LA) and leaf number (LN). Leaf number per plant on any day was calculated from the Hoerl function (Figure 2) fitted between leaf number and accumulated TUs. The quadratic relationship explains the leaf area dynamic with time including leaf senescence. The data on leaf number at different DAS from experiment 1 was used to develop the above-mentioned relationships.

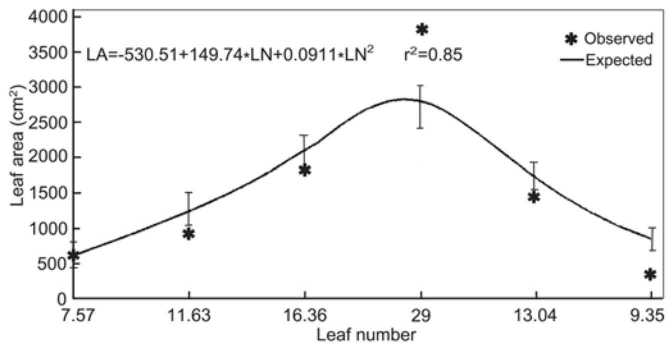

Figure 1: Change in leaf area of sunflower per plant calculated from the quadratic relationship between leaf number and leaf area (data from experiment 1). The vertical bars indicate the standard error of the observed data.

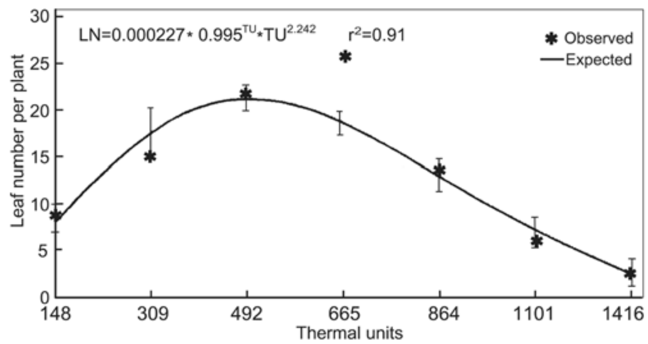

Figure 2: Change in leaf number of sunflower per plant calculated from the Hoerl function between leaf number and thermal time (data from the experiment 1). The vertical bars indicate the SE of the observed data.

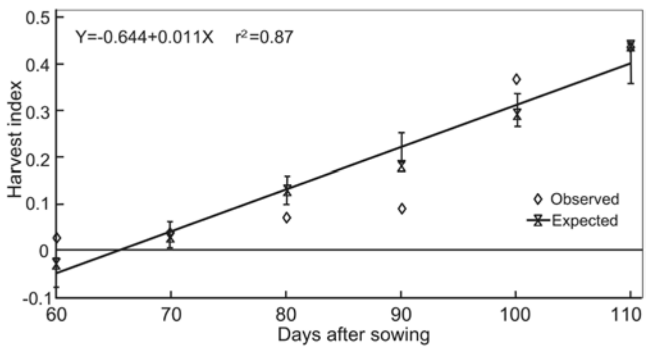

Figure 3: Linear increase in harvest index of sunflower. Anthesis (50% of plants) occurred 55 DAS. While the start of grain filling was 60 DAS. The line is fitted to all the observations recorded in the experiment 1. The vertical bars indicate the SE of the observed data.

Simulation of biomass

Biomass on any day is a function of crop growth rate. Accurate prediction of crop growth rate is important in predicting the biomass. Crop growth rate in turn is a function of amount of cumulative photosynthetically active radiation (PAR, M m^{-2}) intercepted (IPAR) by the canopy and its ability to convert the IPAR into chemical energy (RUE, g MJ^{-1}) (Kiniry *et al.*, 1992; Chapman *et al.*, 1993 and Steer *et al.*, 1993). This can be written as:

$$\text{biomass } (g\ m^{-2}) = f\ (\text{CGR } g\ m^{-2}) \qquad (1)$$

$$\text{CGR } (g\ m^{-2}) = \text{IPAR} \times \text{RUE} \qquad (2)$$

The amount of PAR intercepted by the canopy is a function of leaf area index. The leaf area calculated from the relationship described in the previous section was used to calculate the amount of PAR interception by the leaf canopy using the equation:

$$\text{IPAR} = \text{PAR} \times (1 - e^{-kLAI}) \qquad (3)$$

where, k is light extinction coefficient. The value of k is calculated based on the exponential relationship between the amount of light transmitted by the canopy (T) and changing LAI

$$T = 0.62 \times e^{-0.8LAI}, \quad r^2 = 0.82 \qquad (4)$$

For all simulations the k value of 0.8 was considered (Sridhara, 1997) and RUE was set at 1.05 g MJ^{-1} throughout the crop growth (Trapani *et al.*, 1992).

Simulation of grain growth

Daily grain growth rate was calculated based on the empirical observations that the harvest index (HI) of crops increases linearly during seed growth (Saaldo-Navarro, 1995; Spaeth and Sinclair, 1985; Muchov, 1990; Hall *et al.*, 1990). Field data collected in experiment 1 during grain growth was used to calculate the linear increase in HI during grain growth period (Figure 3). The rate of increase in HI was 0.011 day^{-1}, and this value was used in all simulations. Daily grain growth rate was calculated from the assumed change in HI during grain growth period.

Model calibration

Model was empirically calibrated to predict the effect of irrigation and moisture stress on growth and yield in both experiments by calculating the suitable sensitivity factors (to be discussed later).

Model sensitivity criteria and statistical analysis

The model performance was assessed by the coefficient of determination (R^2) and root mean square deviation (RMSD) as suggested by Grust and Mason (1980) and Keating and Walfula (1992). The observations recorded in this study were statistically analyzed following the procedure given by Gomez and Gomez (1984).

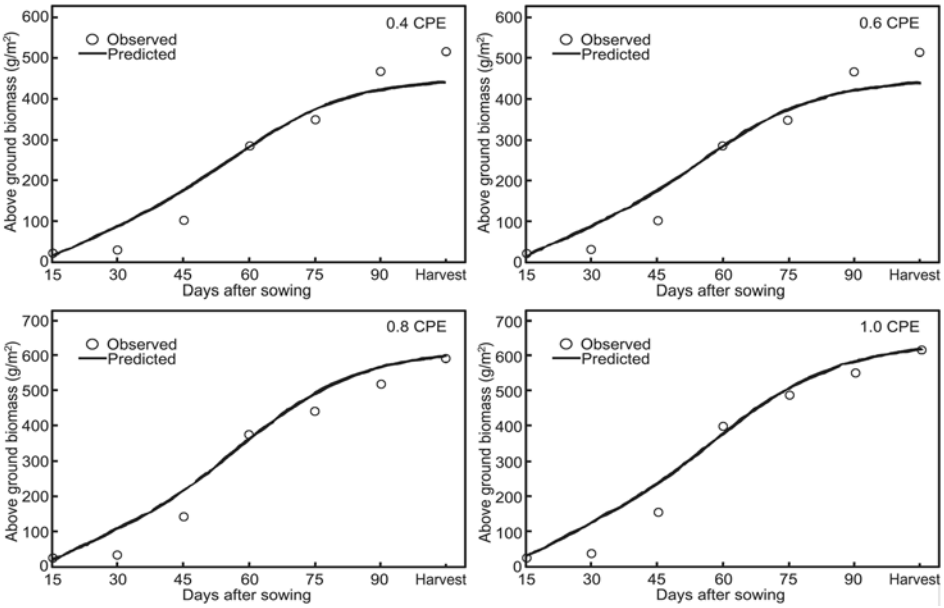

Figure 4: Time trends in simulated and observed biomass as influenced by irrigation regimes

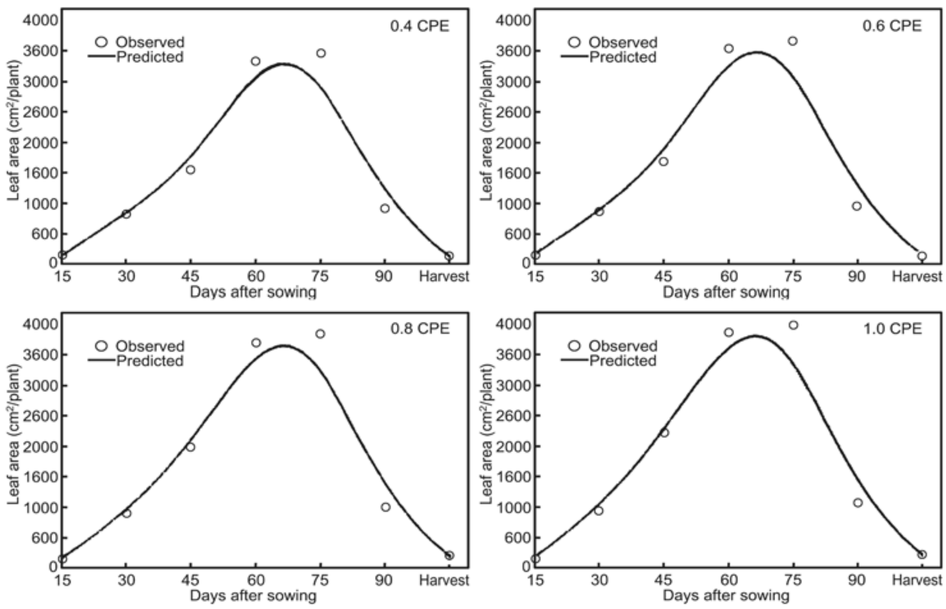

Figure 5: Time trends in simulated and observed leaf area as influenced by irrigation regimes

RESULTS AND DISCUSSION

The combination model was used to predict the growth and yield of sunflower under varied degrees of irrigation regimes and moisture stress experienced by the crop during different growth stages. The model was first used to predict the growth and yield of sunflower under optimal conditions. Then the model was empirically calibrated to predict the growth and yield under water-limited conditions by using suitable sensitive factors. Leaf initiation rate, leaf number and leaf area were found to be most sensitive to soil dehydration in sunflower (Merrin *et al.,* 1982; Yagppan *et al.,* 1982; Sridhara, 1997). In the model, leaf number was multiplied with the sensitive factor S, which ranged from 1.0 (optimal conditions) to 0.3 (under sub-optimal conditions) to simulate the leaf number under sub-optimal (water-limited) conditions, since, if the model leaf area is simulated based on leaf number and the biomass from the IPAR x RUE, IPAR is in turn influenced by LAI and LAI also reflects the plant water status and potential photosynthesis. Hence, the accurate predication of leaf number is important in predicting biomass, grain growth and final yield under different conditions of water supply.

The observed and simulated values for several crop characteristics showed a good agreement. This suggests that the relationships and constants used in the model described the growth and yield of sunflower (cv. KBSH-1) adequately.

Model predictions of the aboveground biomass and leaf area at different growth stages as influenced by different water regimes had a fair degree of accuracy (Figures 4 and 5). The slopes and intercepts of the linear regressions that fitted the simulated/observable relationships for each of the water regimes were not significant (P=0.05) which explained more than 95% of the observed variability (Table 1).

Table 1: Linear regression of the predicted and observed above ground biomass for different irrigation regimes

Irrigation regimes	a	b	r^2	F
0.4 CPE	-57.72 (16.95)	1.18 (0.11)	0.96	112
0.6 CPE	-48.83 (14.84)	1.14 (0.08)	0.97	183
0.8 CPE	-46.12 (16.03)	1.12 (0.08)	0.98	179
1.0 CPE	-45.92 (15.85)	1.04 (0.07)	0.98	206

Values in the parenthesis indicate S.E. of respective constants

Time trends in biomass accumulation and leaf area development (Figures 4 and 5) in four contrasting irrigation regimes showed that the simulated and measured values were close throughout the growing season. However, the model slightly over-predicted the leaf area at peak value in all the treatments. This may be due to the fact that the model did not take into consideration the soil water balance and evapotranspiration in developing the sensitivity factors. The approach followed for simulating the yield under different degrees of moisture stress treatments imposed by withholding water was that the yield under non-stressed treatment was multiplied by the moisture stress scalar (yield reduction factor). The moisture stress scalar was calculated by an exponential decay curve fitted biomass at harvest with time during which the treatment has received moisture stress (Figure 6). Only the final biomass at harvest was considered to calculate the moisture stress scalar since sunflower had a tremendous capacity to recoup its leaf area and final yield once the crop was alleviated from the stress (Rawson and Turner, 1982; Connor and Jones, 1985). Model performance for grain yield and biomass yield was evaluated using the data from both field experiments (except the treatments which were used for the development of the model). A comparison of the simulated grain yield and biomass yield with the measured values showed that the two were quite close to RMSD of 77.85 kg ha^{-1} for seed yield and 12.70 g m^{-1} for biomass yield. A linear regression between the simulated and the measured values for both seed and biomass yield also indicated the ability of the model to predict the seed and biomass yield accurately (Figures 7 and 8). There was a good agreement between the simulated and the observed biomass and grain yields indicating the ability of the model to predict the growth and yield to a certain degree of accuracy.

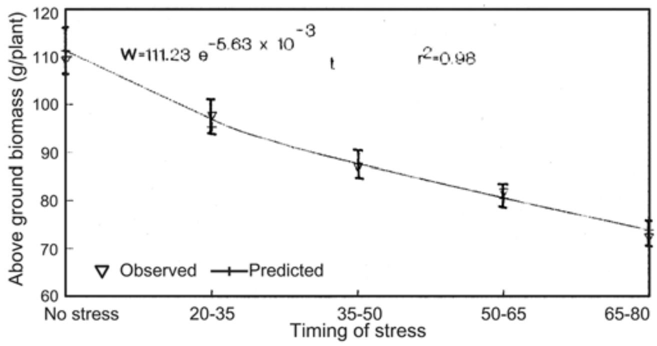

Figure 6: Exponential decay curve indicating the response of sunflower to moisture stress. The vertical bars indicates the SE of the observed data.

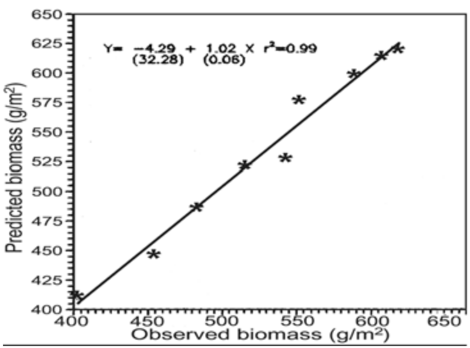

Figure 7: Linear relationship between the simulated and observed biomass at harvest over irrigation and moisture stress treatments.

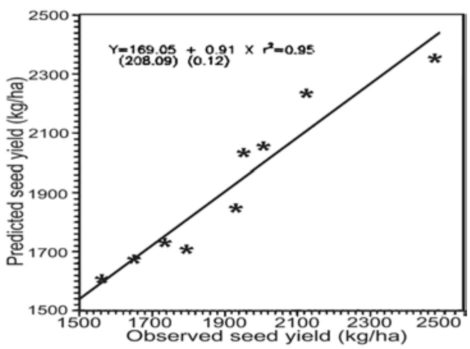

Figure 8: Linear relationship between the simulated and observed seed yields over irrigation and moisture stress treatments.

Finally it can be concluded that the combination model developed with the help of several conservative relationships existing between climatic parameters and plant growth will predict the growth and yield of sunflower with a fair of accuracy under a wide range of moisture regimes apart from empirically quantifying the effect of moisture stress on yield of sunflower. But the model predictions are limited to the range of water regimes tested in this study, as the model does not take the soil water balance into account in predicting the effect of moisture stress on crop development, leaf area, canopy development and radiation use efficiency. However, the model can be used to predict the potential yield of sunflower cultivar KBSH-1 in other locations.

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INFLUENCIA DE IRRIGACIÓN Y DEL ESTRÉS HÍDRICO EN EL MODELO COMBINADO MECANICÍSTICO-EMPÍRICO PARA EL PRONÓSTICO DE CRECIMIENTO Y RENDIMIENTO DE GIRASOL

RESUMEN

El girasol (*Helianthus annuus* L.), uno de los cultivos oleaginosos más importantes, muy a menudo se cultiva en las zonas secas, donde la variación de las precipitaciones hace la producción agricultora riesgosa y donde las plantaciones sufren el estrés hídrico en diferentes fases de crecimiento. Como ayuda en la evaluación de los riesgos productivos, se usan modelos para simulación en agricultura. Este estudio describe el desarrollo y el examen de un modelo combinado mecanístico-empírico, para el girasol. Este modelo utiliza varias relaciones conservativas, con el fin de definir el desarrollo de la superficie de la hoja, como función del número de hojas, y el número de hojas como función de las unidades térmicas acumuladas. La acumulación de la biomasa se simula como función de la fracción de la absorción de radiación activa desde el punto de vista de fotosíntesis y la eficiencia de la utilización de radiación. El desarrollo de la semilla se simula del incremento lineal del índice de cosecha durante el tiempo. Este modelo está calibrado empíricamente, para prever la influencia de la irrigación y del estrés hídrico, en el crecimiento y rendimiento de girasol, mediante el desarrollo de los correspondientes factores de sensibilidad. El modelo ha previsto, de la manera satisfactoria, la biomasa aérea, la superficie de la hoja y el rendimiento final de girasol dependiendo de la irrigación y del estrés de la humedad.

EFFET DE L'IRRIGATION ET DU STRESS DÛ AU MANQUE D'HUMIDITÉ SUR UN MODÈLE MÉCANIQUE ET EMPIRIQUE POUR LA PRÉVISION DE LA CROISSANCE ET DU RENDEMENT DU TOURNESOL

RÉSUMÉ

Le tournesol (*Helianthus annuus* L.) est l'une des cultures oléagineuses les plus importantes; il se cultive assez souvent dans des régions de sécheresse où les variations dans les précipitations rendent la production agricole risquée et où les cultures subissent un stress dû au manque d'humidité au cours de différentes phases de leur croissance. Pour pouvoir évaluer les risques de production, on utilise des modèles de culture. Cet article décrit la croissance et l'évaluation d'un modèle combiné empirique et mécanique du tournesol. Ce modèle utilise quelques rapports conservateurs pour définir le développement de la surface feuillue comme fonction du nombre de feuilles et le nombre de feuilles comme fonction d'accumulation d'unités thermiques. L'accumulation de la biomasse est simulée comme fonction de fraction d'assimilation photosynthétique de l'énergie lumineuse et d'efficacité d'utilisation de l'énergie lumineuse. La croissance de la semence est simulée de l'accroissement linéaire de l'index de récolte au cours du temps. Le modèle a été calibré empiriquement pour que soient prédits la croissance et le rendement du tournesol sous l'effet de l'irrigation et les effets du stress dû au manque d'humidité à l'aide du développement de facteurs de sensibilité correspondants. Le modèle a prévu de façon satisfaisante la biomasse aérienne, la surface feuillue et le rendement final du tournesol sous l'effet de l'irrigation et du stress dû au manque d'humidité.