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A data base for scaling up from the leaf to the canopy

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Abstract

A data base was generated for quantifying effects of thermal time (degree-days) on the appearance of new leaves, the expansion of such leaves to maximum area, their death, the appearance of new internodes below the node associated with such leaves, and the extension of these internodes to maximum length. The data base for a list of crop (agronomic and horticultural), weed, and native Tallgrass Prairie plants has been summarized, with equations for the above events as a function of degree days, with appropriate base temperatures and maximum cut-off temperatures, in a Java applet which is available at a website with the URL <http://th190-50.agn.uiuc.edu>. Associated graphical plots such as shown in this paper are also given. Branching behavior was accounted for. These events predict the effect of thermal time on leaf age and its height in the plant canopy, both important factors needed for upscaling functions for leaf behavior to those for behavior of the plant canopy. The data base is evolving to include coefficients for other species. Coefficients are used to predict the leaf area index of the canopy, which is important for predicting evapotranspiration from the crop and the protection of the soil from erosion.

Additional key words: *Gossypium hirsutum*; internode; leaf area index; node number; plant height; stem; *Zea mays*.

Introduction

The vegetative canopy Leaf Area Index (LAI) is an important factor controlling canopy photosynthetic rate, transpiration rate, evaporation rate from the soil surface exposed to the sun, and protection of the soil from erosion.

The canopy also acts as a storage mechanism for protein-N which can be translocated to growing seeds at an appropriate time during the life cycle of the plant.

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Age effects on leaf photosynthetic behavior and leaf placement in the canopy play a major role in controlling radiant energy interception and canopy gas exchange characteristics. The growth of leaves and stem components of the canopy are controlled by temperature as well as the materials (water, nitrogen, saccharides) budget and associated stresses in the root-shoot system. Begonia *et al.* (1987) reported leaf appearance and death events as a function of real time for soybean [*Glycine max* (L.) Merr.] and maize [*Zea mays* (L.)] cultivars and genetic strains; Hesketh *et al.* (1988) reported the same for maize leaves and internodes, along with dry mass values. Temperature effects on such events need to be taken into account for predictive purposes.

We report here a data base for predicting the effects of thermal time or degree days on the appearance of new leaves in the canopy after planting or resumption of new growth in the spring. The data base also enables prediction of the appearance of new, fully-expanded, and dead leaves (three events) in the canopy, in addition to the appearance of new as well as fully extended internodes below such leaves. The prediction of such phenological events provides an estimate for the placement and age of each leaf in the canopy. Canopy radiant energy interception and leaf gas exchange models can then be used to predict canopy gas exchange rates as a function of the environment.

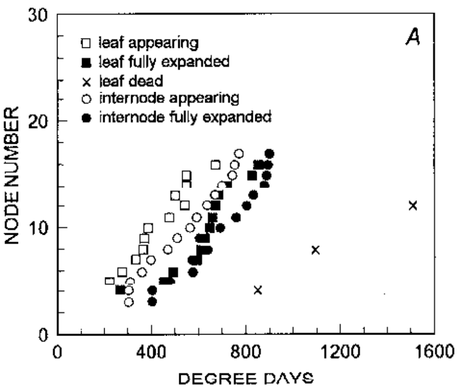
Materials and methods

Plants were grown during the 1995-6 growing seasons on or near the Crop Science South Farm in Urbana, IL, USA (40.12 deg. latitude, 88.17 deg. longitude), near a standard USA weather station which kept daily records of PAR. Crops were fertilized with 20 g(N) m^{-3} [200 kg(N) per ha] and were irrigated when showing stress.

Lengths of growing leaves and internodes were measured on the same test plants [six plants for maize (*Zea mays* L.), three plants for cotton (*Gossypium hirsutum* L.) excluding three other plants with damaged growing points, repeated on three cotton cultivars other than the one reported on here] every four to seven days during the growing season. Leaf lengths were converted into area using equations derived from area : length measurements using an area meter [leaf area = $1.244x^2 - 4.725x + 9.253$, where x = leaf length, $r^2 = 0.928$, $n = 41$ for cotton cultivar Deltapine 50, and = $0.119x^2 - 2.452x + 22.672$, $r^2 = 0.975$, $n = 79$ for maize Pioneer hybrid 3972). Dates of flowering and branching patterns were recorded. Degree day values were calculated using values from a nearby standard weather station [for the crop examples given here, we used 8 °C as a base temperature for maize and 12.5 °C for cotton]. Horticultural and agronomic crop plants were grown in row spacings and densities used commercially—0.76 m between rows, eight plants per meter in the row for cotton and four per meter for maize, with test plants protected by border rows. Weed plants were usually in or near the crop row, sometimes in a stand gap, such as might occur with cultivation. Native plants were taken as distributed in a nearby reconstructed Tallgrass Prairie. Java, an object-oriented and internet-based programming language, was used to integrate equations from the data base into syntheses of phenological events as a function of degree days (or real time) and leaf area placement with plant height. Plant, soil, and weather values are included at our website, as well as a simple model for estimating how carbon and water budgets affect leaf and internode growth.

Results and discussion

Values for maize and cotton (Fig. 1) are taken directly as examples from the website



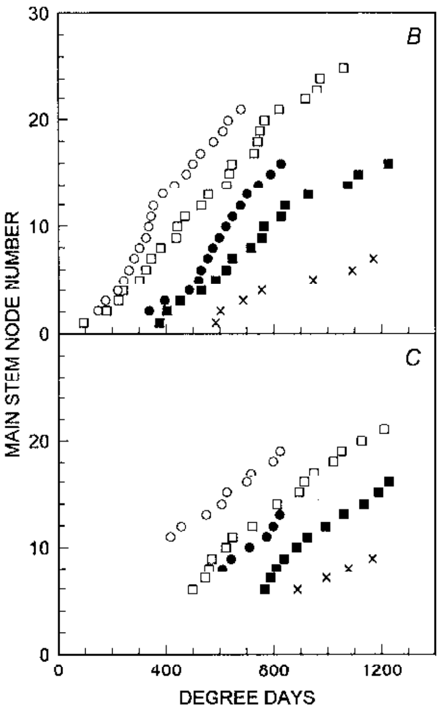


Fig. 1. Maize (*A*), and cotton cv. Deltapine 50 mainstem (*B*) and first sympodial branch (*C*) leaf and internode phenological events *vs.* degree days for the growing season. In *C*, leaves were considered to "appear" when their area exceeded 1 cm^2, and newly-formed internodes were counted when internode length exceeded 0.1 cm. Similar plots were also made for other cultivars and for the second sympodial branch leaf (not shown).

data base for 19 other species (as of early 1997, others are being added). The data base consists of equation coefficients and associated r^2 values, including maximum areas per leaf and lengths per internode as a function of mainstem or branch (tiller) node number. Fig. 2 shows the relation between area per leaf or sympodial branch and plant height at various accumulated degree day values during the growing season. Branch leaf area would be expected to vary with planting density. Fig. 3 gives the relationship between LAI and degree days. 1990-1997 daily maximum and minimum temperatures from a standard weather station are also provided at the website, along with the option of converting from degree days to real time during the growing season. Growing degree days only approximates the many complex ways that plants respond to temperature; others may wish to explore the data base with a more sophisticated temperature-reponse model, using the 1996 weather data to generate real time data.

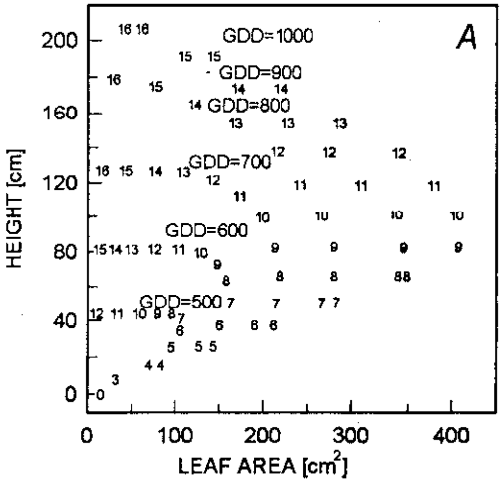
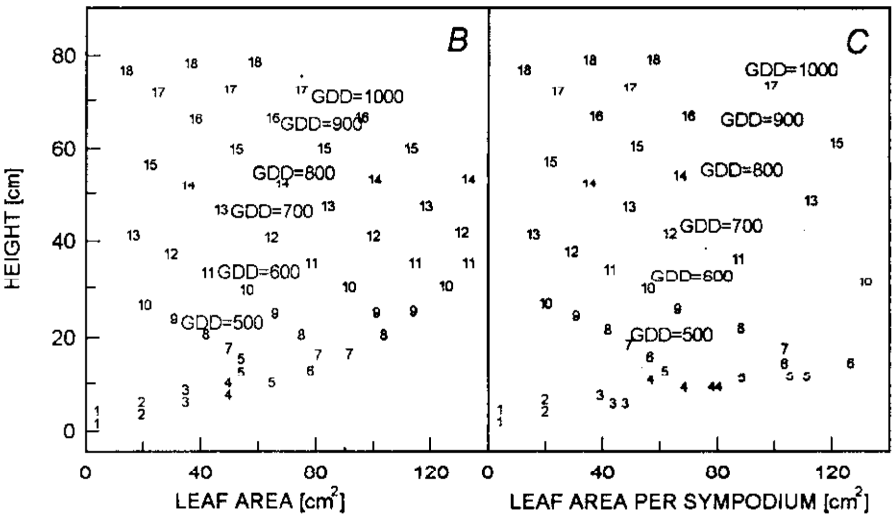


Fig. 2. Maize cv. Pioneer 3972 (*A*) and cotton cv. Deltapine 50 mainstem (*B*) and sympodium (*C*) leaf area *vs*. plant height and degree days (GDD). Numbers indicate leaves above the coleoptile leaf (*A*) or cotyledonary node (*B, C*).



Alm and Hesketh (1990) described a model for radiant energy interception, taking into account vertical placement of leaves inside the canopy and the position of the sun, much as others have done earlier (*e.g.*, Ross 1970). This model is being reprogrammed into Java; the data base reported here will be useful in further studies with that model.

Fu and Hesketh (1996) developed a model for soybean taking into account water stress effects, using evapotranspiration equations based upon the prevailing LAI. The model used logistic growth equations for leaf expansion and internode extension. Stress effects on expansion and extension were arbitrarily a function of the prevailing soil water content and evaporative demand; such relationships are difficult to validate experimentally. Others have taken saccharide stress into account; N stress is rarely a factor in soybean production systems. The Fu and Hesketh model also predicts the effect of photoperiod and temperature (independent of degree days) effects on flowering and total mainstem nodes produced. The flowering of soybean cultivars grown at the Urbana and more southerly latitudes are very sensitive to photoperiod and temperature. We are in the process of adding generic stress modules based upon prevailing mass balances between sources and sinks in the soil-plant-air systems involved; so far we have accounted for water and carbon flow through the system, both based on LAI values generated from the data base. Stress values so generated are used to predict how much leaf expansion and internode extension slows down. Our data base, of course, can be used to extend the predictablity of other crop-specific or generic plant growth and yield models.

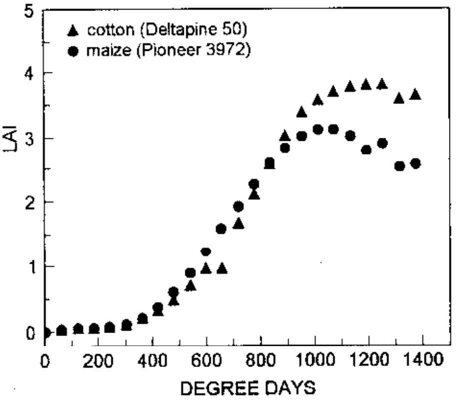


Fig. 3. Leaf area index (LAI) for maize and cotton stands as a function of degree days over the growing season, as predicted by the database model.

Leaf age effects on stomatal behavior, such as response to atmospheric vapor pressure deficit, and on chloroplast photosynthetic behavior are important factors controlling leaf gas exhange with the atmosphere. Leaf height and angle control light interception within the plant canopy. Our data set provides some of this information for the first time for 21 plant species; values are available for more. Thus the data base does exist, is evolving, and is currently available at a website on the internet, with associated documentation such as given here.

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