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A COMPARISON OF DEGREE-DAY MODELS FOR PREDICTING PECAN NUT CASEBEARER

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ABSTRACT

The pecan nut casebearer (PNC) has become a serious concern in Mesilla Valley, southern New Mexico. It is a potentially devastating insect to pecan trees that has long been a problem in Texas. Accurate predictions (e.g., day of year) of PNC life stages, particularly first significant nut entry (FNE), are essential to any successful operations designed to control damage to nut crops. Computer models, based on climatic parameters, have been effective in predicting PNC life stages in pecan-growing areas of the Midwest, Mexico, and Texas. The two most popular models use either heat degree-days (Texas model) or both heat and chill degree-days (Sparks model) to predict PNC development. This project uses historical weather data from various locations within the Mesilla and El Paso valleys to analyze model predictions, and where possible to compare predictions with actual field observations. The results indicate that the Texas model predicts a more consistent day of year (153 +/- 3) than the Sparks model (149 +/- 6) for FNE. This is probably attributable to the variability in winter "chill" accumulation from year to year in the region. The Sparks model is more sensitive to changes in temperature averaging methods, and preliminary data suggests that the Sparks model more accurately predicts observed FNE than the Texas model.

Texas pecan growers have long considered the pecan nut casebearer (PNC) to be their major insect threat (Thomas and Hancock 1968; Harris 1998). It has also long been understood that in order to exercise control over PNC crop damage, one must anticipate the stages of the insect's life cycle (Gill, 1917; Bilsing, 1926). There are very narrow windows of opportunity to control this pest by chemical and non-chemical (i.e. *B. thuringiensis*) means. Previous research has repeatedly shown that, of all the PNC's stages, the first summer generation larvae are the most damaging. Effective management requires control of these larvae prior to nut entry (Bilsing 1926; Davis 1995; Gill 1917; Sparks 1995). There are no systemic insecticides for PNC, therefore the first generation's larval stage must be targeted during the two to three day feeding stage between egg hatch and nut entry (Knutson and Ree, 1995; Sparks 1995). Insecticides, if necessary, are applied at first significant nut entry (FNE), two or three days after first summer generation eggs hatch. Nut entry is considered significant when about 1% (Sparks, 1995) or 1 to 3% (Ring, 1981) of nut clusters inspected have been entered by PNC larvae.

Several methods for predicting when a damaging PNC population will occur have been devised and implemented over the years. Historic methods include: relying on empirically determined calendar dates, field observations of moth emergence or first nut entry, or on pecan phenology (e.g., waiting for the tips of the nutlets turn brown) (Ring, 1981; Sparks, 1995). Predictions were later augmented by monitoring PNC pupation and

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adult emergence using banding and blacklight traps (Bilsing, 1927; Ring and Harris, 1983; Sparks, 1995; Thomas and Hancock 1968). Each of these methods have drawbacks: key dates in PNC phenology vary by locality and from year to year (Gill, 1917; Ring, 1981), constant scouting is prohibitively labor intensive and time consuming, aspects of pecan phenology differ between varieties (Ring, 1981), blacklight traps collect non-target insects, and banding may not catch enough larvae to accurately time treatments (Thomas and Hancock 1968).

In recent years, as the technology became more available, computer models for predicting life cycles of agricultural pests have grown in popularity and accuracy (Mowitz and Peterson 1997). The first predictive PNC model, based on daily ambient air temperatures, was developed by Ring and Harris at College Station, Texas in the early 1980s (Ring and Harris 1983). The Texas model assumes the PNC life cycle, including FNE, can be predicted from ambient spring air temperatures. About fifteen years later, Darrell Sparks at the University of Georgia developed a second computer model for predicting FNE (Sparks 1995). The Sparks model is also based on ambient air temperatures, but includes winter as well as spring temperatures. The contemporary development of the Internet offers easy and often free access to local weather data, making such models practical for major and gift-of-nature producers alike.

Systematic investigations of the PNC are just beginning in the Mesilla Valley of New Mexico and the El Paso Valley of Texas, so observational experience with FNE in the region is scarce. The purpose of this project is to apply both the Texas and Sparks models of PNC development to these areas. Computer code was created that implements both models. Historical weather data, in particular average air temperature, was used to estimate the average day of year and ranges of calender days where FNE is most likely to occur. The results were compared against the sparse amount of available field data.

MODELING METHODOLOGY

The Texas and Sparks models base their predictions of PNC development on the temperatures experienced by the insect population over time. The degree-day is the unit that combines temperature and time, and can be used to account either for heating or chilling. One heat degree-day is accumulated for each degree the daily average temperature is above the selected base temperature and one chill degree-day is accumulated for each degree the daily average temperature is below the selected base temperature. The degree-day is commonly referred to as a measure of physiological time.

The procedure for calculating cumulative degree-days is:

$$^{o}D = \sum_{i=1}^{n} (Ta - Tb)_i \quad [1]$$

where ^{o}D is the degree-days accumulated between day 1 and n, T_a is the average daily temperature, and T_b is the base temperature. Degree-days calculated using the centigrade scale are five-ninths as big as degree-days calculated using the Fahrenheit scale. Metric units are used in this study.

The calculation of T_a for the original Texas and Sparks models was done by simply adding the daily minimum air temperature to the daily maximum air temperature and dividing the sum by two:

$$T_a = \frac{(T_{\max} + T_{\min})}{2} \quad [2]$$

where T_{max} is the daily maximum air temperature, and T_{min} is the daily minimum air temperature. Until recently, daily minimums and maximums were the only air temperatures reported by most weather services in the United States. This has therefore been the *de facto* method of figuring daily average temperatures.

With the advent and availability of automated electronic equipment, methods of climate data collection are changing. At all New Mexico weather network stations climate data is collected by Campbell dataloggers that measure air temperature at ten-second intervals, from midnight to midnight. The reported daily average is the numerically integrated average of those readings:

$$T_a = \sum_{i=1}^{n} \frac{T_i}{n} \quad [3]$$

Where n is the number of temperature readings taken in a day: 8 640 ten-second readings. This method of averaging more accurately reflects the true average temperature.

These degree-day models require the selection of a start date to begin the accumulation of heating or chilling degree-days, and a base temperature for Eq. [1]. Ring and Harris (1983) used PNC field data collected by Bilsing (1926; 1927) to correlate the insect's life stages with accumulated heating degree-days. Sparks (1995) obtained field data from a variety of sources to evaluate the correlation of FNE with the interaction of heating and chilling.

The Texas model. The Texas model (Ring and Harris 1983), originally designed for the College Station, Texas region, uses a start date of 12 March and a base temperature of 3.3°C. Based on historic PNC and weather data, the model predicts that the first overwintering generation adults appear after the accumulation of 750.2°D, and FNE occurs at 1017.3°D.

The Texas model is generalized for use in locations outside College Station by modifying the start date according to the number of frost-free days (FFD) in the region. One day is added or subtracted to College Station's start date (12 March) for every 2.72 fewer or greater FFD a region has compared to College Station (Ring et. al. 1983). This presents a problem for Mesilla Valley, where the length of the frost free season is more variable than that of College Station. A regional (non-weighted) average of 211 frost free days was used.

The frost-free period is sometimes called the "freeze-free" season (NOAA 1994) or the "growing season" (Kunkel 1985). It is defined as "the mean number of days between the mean date of last spring freeze (0°C) and mean date of first fall freeze" (Ring et. al. 1983; pg. 489).

Sparks Model. The Sparks FNE model (Sparks 1995) is a modification of Sparks' earlier pecan budbreak model (Sparks 1993), which predicts budbreak based on the interactive effects of chilling (or rest) in the winter and heating in the spring. The Sparks model accumulates chilling units from 1 December through 28 February, and uses a heating start date of 1 February. The base temperatures are 9.4 and 13.9°C for chilling and heating respectively.

The number of heating units required for FNE to occur is predicted from the quantity of chilling units accumulated. The equation used to evaluate the combination of chill and heat is:

$$1/Y = 0.0037259 \quad [1 - 0.1e^{-0.0028069(x-574.9638969)}] \qquad [4]$$

where $1/Y$ is the heat accumulated from 1 February until FNE, e is the exponential function, and x is the accumulated chill.

Weather data. Weather data was obtained from two sources. The majority was downloaded from the New Mexico State network's free internet service (http://weather.nmsu.edu). All networked Hatch and Mesilla Valley stations were examined, and all available data for those stations was used. They are Berino, Derry, East Mesa (NMSU golf course), NWS Las Cruces (police station), the Fabian Garcia Horticultural Experimental station (FGHF), the Jornada Experimental Station, and the Leyendecker Plant Science Research Center (PSRC).

Two weather stations from the national cooperator network (operated by the National Climate Data Center, or NCDC) were also used: the El Paso Airport station and the State University station in Las Cruces, New Mexico. El Paso data came from two different sources: January 1948 through December 1996 from the free internet service (http://climate.usu.edu) provided by Utah State University, and data for 1997 and 1998 from the El Paso National Weather Service internet site (http://nwselp.epcc.edu) on the Rio Grande Freenet. Las Cruces data also came from two different sources: April 1959 through 1992 from a CD-ROM available from the NCDC, and January 1994 through 1997 also available at the Utah State University site. The weather stations are summarized in Table 1.

PNC data. Rigorous model verification is difficult because very little PNC data is available for Southern New Mexico and El Paso. The available data was not consistently gathered (i.e. collected in the same manner and from the same location from year to year) and must therefore be used with caution.

Jim Davis (1995) made available pheremone trap data from a 1994 study conducted in the El Paso area. 1995 pheremone trap data was obtained from the Texas A&M extension office in El Paso. Tracey Carillo provided pheremone trap data collected in 1997 on Stahmann Farms in Mesilla Valley.

Ring and Harris (1983), in their examination of historic PNC data, found a strong correlation between first significant nut entry and 65% emergence of the overwintering generation. Pheremone traps only capture male adult moths, and the female segment of the population emerges about 3 days after the males (Ree 1998). Other research (Ree 1998) shows nut entry to occur 12 to 16 days after the first males are trapped. These interpretations are consistent and both considered good first approximations. Model predictions were evaluated accordingly.

RESULTS AND DISCUSSION

Temperature averaging. Running the model with numerically integrated average temperature input, Eq. [3], predicted earlier FNE than when the model was run with temperatures calculated by averaging daily maximums and minimums, Eq. [2]. This effect is much more pronounced for the Sparks model. Evaluating the Sparks model for a fifteen year period at PSRC, FNE predictions using Eq. [3] range from 2 to 12 days earlier (mean = 6.9) than predictions for the same time period using Eq. [2]. Figure 1 illustrates the effect choice of temperature averaging has on FNE prediction, and Figure 2 shows how the methods compare on a day-by-day basis.

The Texas model is less sensitive to the substitution of Eq. [2] for Eq. [3]. In the same scenario, Texas model predictions run from a day earlier to five days later (mean = 2.3 days later).

Frost-free days. Table 2 summarizes average FFD, as calculated at each weather station. The variability is evident in the standard deviation, which is typically 20 to 30 days (the one exception, Derry, is based on only two years' data).

First significant nut entry predictions. Sparks FNE model predictions are consistently earlier than those of made by the Texas model, excepting springs following warm winters. 1994 was an unusually warm winter in the Mesilla Valley, so for many stations the Texas model predicted an earlier FNE for 1995. Figure 3 depicts how the two models differ, over a period of 50 years in El Paso.

Analyzing by weather stations, the standard deviation of the day of FNE is two to three times greater for Sparks model predictions than for the Texas model predictions. This results in calendar ranges for FNE (based on three standard deviations) of 14 to 23 days for the Texas model, and 9 to 57 days for the Sparks model, depending on the weather station. The averages and expected ranges for FNE are summarized in Table 3 by weather station.

Based on the limited PNC data for the region, it appears both models tend to predict FNE later than observed. The Sparks model appears, consistently, to be more accurate. Available data points compared with relevant model predictions are recounted in Table 4.

CONCLUSIONS

Because of the scarcity of consistently gathered PNC data at this time, explicit judgements regarding the models' accuracy for the region are impossible. Tentatively, the Sparks model FNE predictions appear to be more accurate than the Texas model. It is possible that customizing the Texas model for the arid southwest, by reparameterization or by an improved estimation of FFD, will ameliorate its accuracy.

A common, and often valid, complaint regarding the PNC models is that they are unreliable, or inconvenient. These criticisms are sometimes true. There is, however, an interplay when constructing or working with agricultural models between wanting to provide a service or product that is useful to producers, and gaining insight into the system under consideration, in this case the behavior of the PNC in the Doña Ana County region.

The process of trying to model such systems is often helpful in quantifying the influence of variables, or in identifying previously unnoticed relationships and gaps in knowledge. A detail that currently has researchers and pecan growers puzzled in the desert southwest is: Why hasn't the PNC become a problem? It is listed by East Texas growers as their major pest concern, yet after at least six years in the Mesilla Valley the PNC has not been seen to cause significant damage. Why not? The answer is likely to lie in environmental or climatic differences, or both. A better understanding of model parameters like base temperatures, FFD, and heat and chill units will doubtless lead to improvements in PNC control, and in pecan management generally.

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Figure 1. Sparks model predictions of first significant nut entry for PSRC, using two methods of temperature averaging

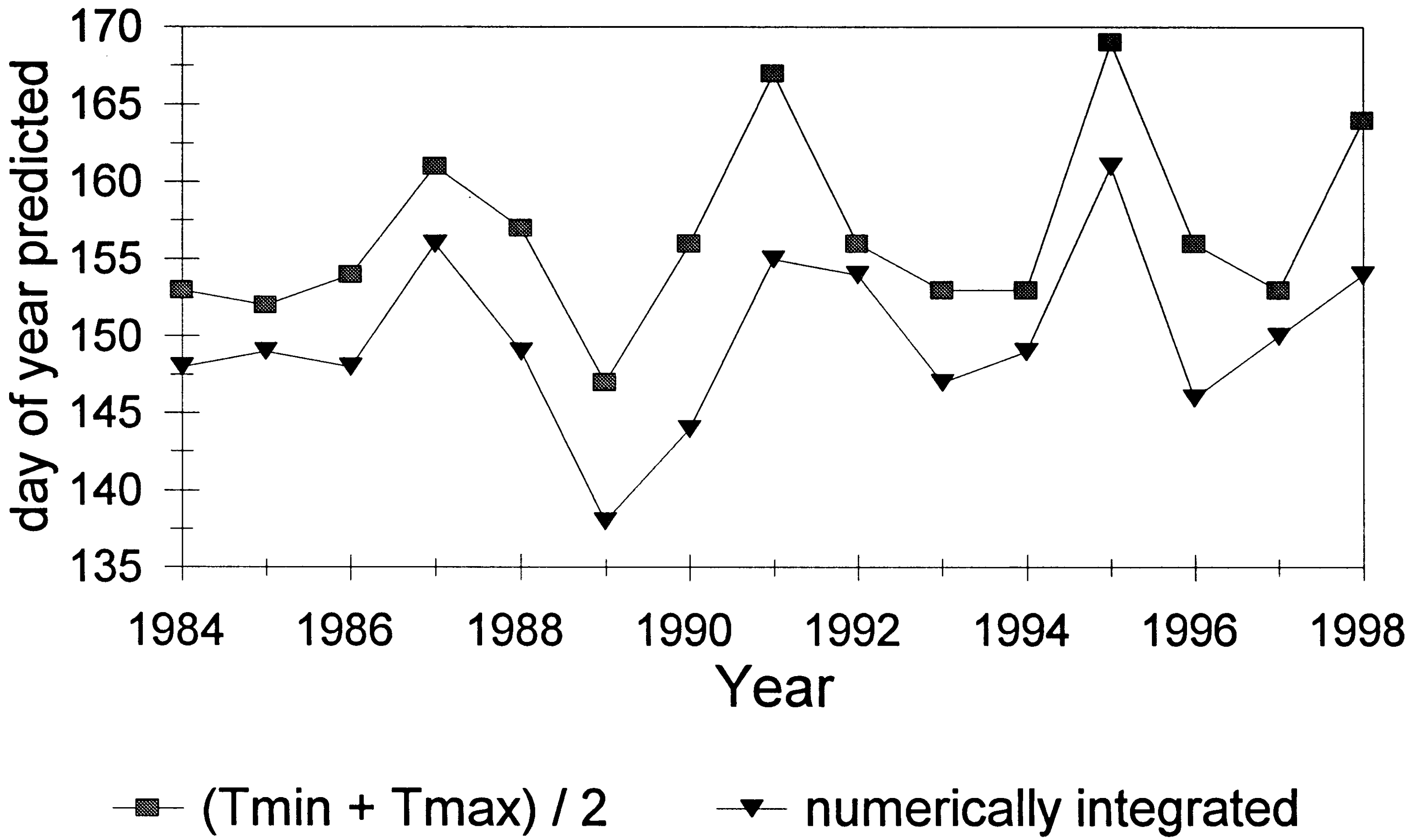

Figure 2. Temperature averaging methods compared for PSRC, month of May 1996.

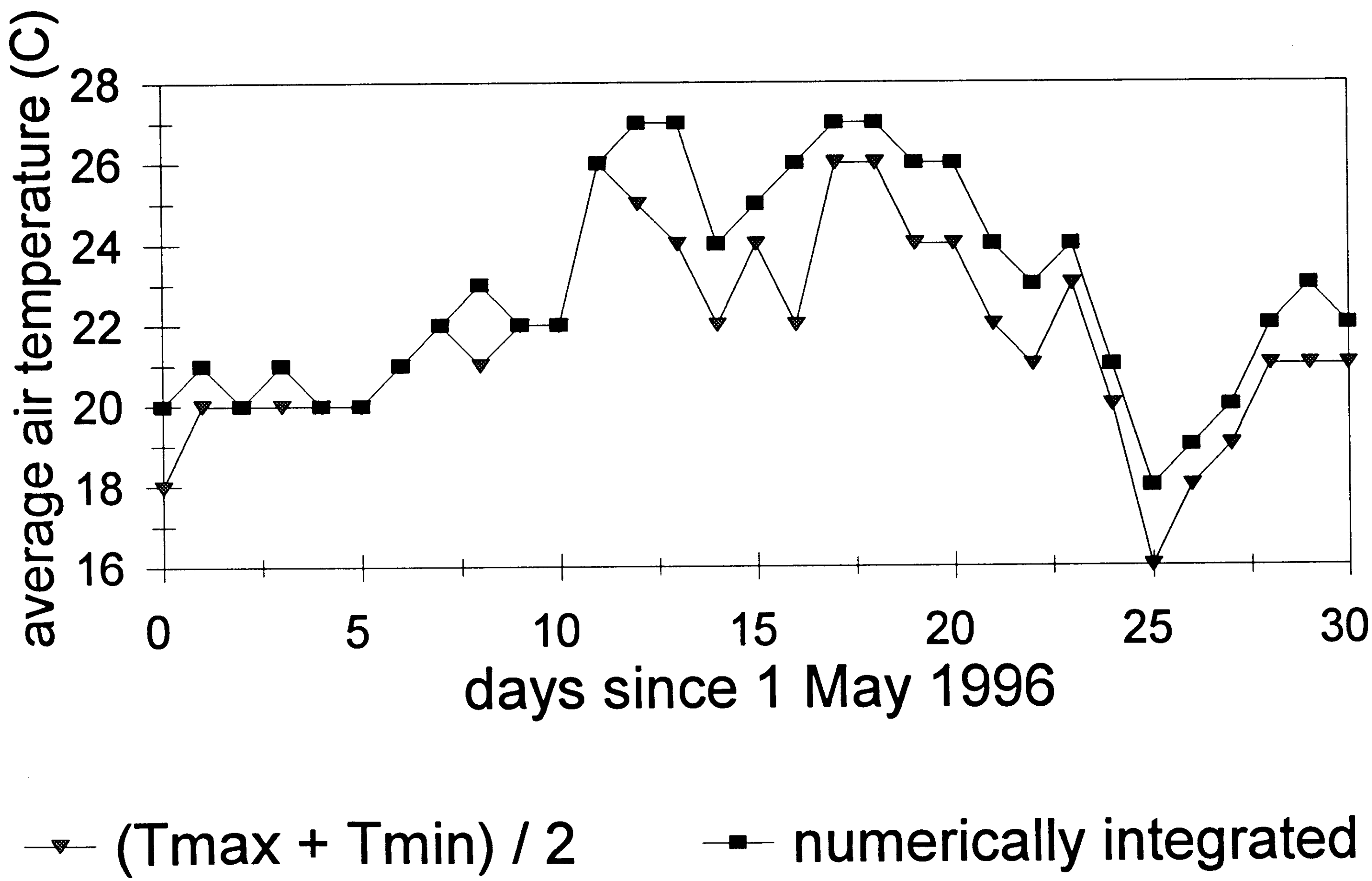

Figure 3. Predicted first significant nut entry at El Paso. Texas and Sparks models compared, with known data points included.

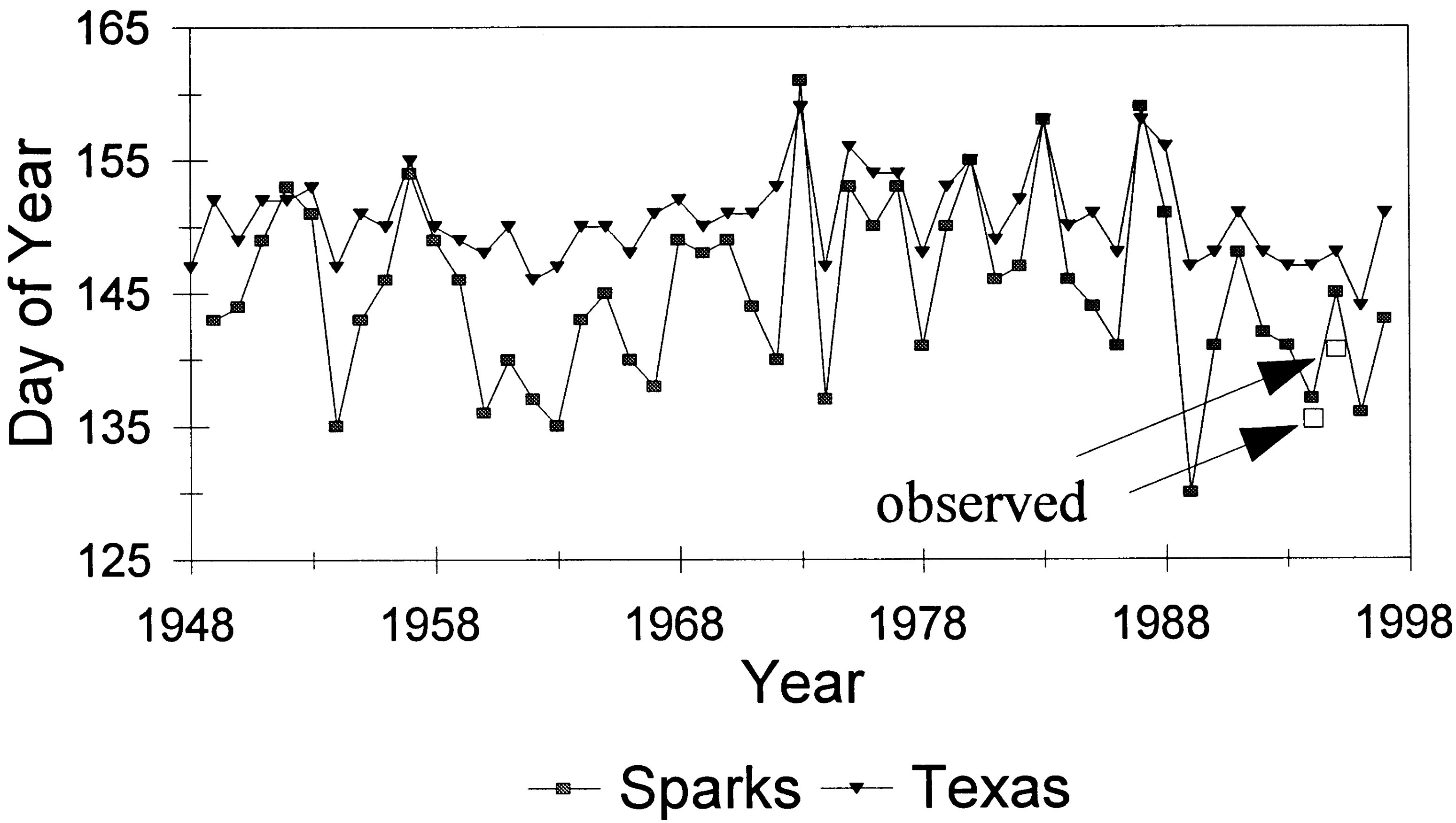

Table 1. Summaries of weather stations

Station	Location	Lat.	Lon.	Elev. (m)	Environment
Berino	Two miles west of Berino on route 478	32° 03' 50.4"N	106° 40' 12"W	1147	Bare soil for 25 feet, crop cover to the north and west, trees and buildings to the south and east
Derry	Derry, West of I-10 highway	32° 47' 47.2" N	107° 17' 9.6" W	1255	Sand for 50 ft, then crop cover
NWS, Las Cruces[a]	South-central Las Cruces, on NMSU campus	32° 16' 56.0" N	106° 45' 35.9"W	1183	Grass cover for 100 feet, then asphalt to the east, bare soil and buildings west and south, crop cover to the north
State U; National Weather Service, Las Cruces	South-central Las Cruces, on NMSU campus	32° 16' 56.0" N	106° 45' 35.9"W	1183	Grass cover for 100 feet, then asphalt to the east, bare soil and buildings west and south, crop cover to the north
Fabian Garcia Horticultural Experimental St.	Two miles east of Mesilla; southern outskirts of Las Cruces	32° 16' 43.02" N	106° 46' 15.6"W	1183	Grass cover for 25 feet, then crop cover
Jornada Experimental St.	25 miles northeast of Las Cruces	32° 31' 17" N	106° 47' 50" W	1359	Range land, mostly grass and shrubs
Leyendecker Plant Science Research Center	15 miles south of Las Cruces	32° 12' 4.44"N	106° 44' 32.88"W	1168	Grass cover for 25 feet, then crop cover
East Mesa	On NMSU's Golf course	32° 17' 4.44"N	106° 43' 54.78"W	1265	Grass surrounded by golf course
El Paso airport	until 1995, EPIA; after 1995, Santa Teresa NM	31° 48'N	106° 24'W	1062	

a). Though named "NWS," this station is actually maintained by the New Mexico state network. The reason for the name is that it is located next to the actual NWS weather station (State U, above). Hence both stations have the same latitude, longitude, and elevation.

Table 2. Frost-free (FFD) day averages and standard deviations (sd)

Station	Avg. FFD	SD	Years of data
Derry	194	8.48	2 (1996 - 1997)
East Mesa	203	25.47	7 (1991 - 1997)
El Paso	232	21.35	50 (1948 - 1997)
Fabian Garcia	206	38.06	10 (1988 - 1997)
Jornada	212	24.37	7 (1991 - 1997)
NWS - Las Cruces	225	21.02	7 (1991 - 1997)
State U. - Las Cruces	210	20.44	37 (1960 - 1997; missing 1993)
Plant Science Center	198	31.97	15 (1983 - 1997)
Average	210	23.89	

Table 3. Summary of first significant nut entry averages and ranges, according to weather station.

Station	Years of data	Day of year ± sd		Mean (± 3 sd)	
		Texas	Sparks	Texas	Sparks
Berino	2	151.5 ± 2.1	146.0 ±1.4	May 25 - Jun 7	May 22 - May 30
East Mesa	7[A]	153.7 ± 2.6	151.7 ± 6.1	May 26 - Jun 10	May 13 - Jun 19
Fabian Garcia	11	151.8 ± 3.0	145.3 ± 9.4	May 23 - Jun 10	Apr 27 - Jun 22
Jornada	8[A]	150.4 ± 2.9	145.1 ± 5.9	May 22 - Jun 8	May 8 - Jun 12
NWS (Las Cruces)	8[A]	152.1 ± 3.2	148.7 ± 5.2	May 23 - Jun 11	May 13 - Jun 13
PSRC	16[A]	154.4 ± 3.9	149.9 ± 5.5	May 24 - Jun 14	May 13 - Jun 15
State U.	37[A]	156.9 ± 3.7	157.3 ± 6.9	May 26 - Jun 17	May 17 - Jun 27
El Paso	50[A]	150.7 ± 3.3	145.1 ± 6.8	May 21 - Jun 10	May 5 - Jun 14

A) indicates that for the Sparks predictions there is one less year with which to make estimates, because Sparks prediction requires data from the preceding year.

Table 4. Observed first significant nut entry, interpreted from trap data, compared with Sparks and Texas model predictions.

Station and year	Sparks	Texas	FNE, based on trap data
El Paso - 1994	May 17 (137)	May 27 (147)	May 16 (136)
El Paso - 1995	May 25 (145)	May 28 (148)	May 20 (140)
PSRC - 1997 (Stahmann)	May 30 (150)	Jun 4 (155)	May 26 (146)
FGHF - 1997 (Stahmann)	May 26 (146)	Jun 2 (153)	May 26 (146)