A Comparison of Two Peanut Growth Models for Oklahoma

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ABSTRACT

Growth simulation models provide potential benefit in the study of peanut (*Arachis hypogaea* L.) production. Two physiologically-based peanut simulation models of varying complexity were adapted and calibrated to simulate the growth and yield of spanish peanut under Oklahoma conditions. Field data, including soil moisture measurements and sequential yield samples, were collected at four sites during the 1985 growing season. An automated weather station provided the necessary climatic data for the models. PNUTMOD, the simpler model originally developed for educational purposes, requires seven varietal input parameters in addition to temperature and solar radiation data. The seven model parameters were calibrated using data from two of the four field sites, and model performance was evaluated using the remaining two data sets. The more complex model, PEANUT, simulates individual plant physiological processes and utilizes a considerably larger set of input parameters. Since PEANUT was developed for the virginia type peanut, several input parameters required adjustment for the spanish type peanut grown in Oklahoma. PEANUT was calibrated using data from all four study sites. Both models performed well in simulating pod yield. PNUTMOD, which does not allow for leaf senescence, did not perform as well as PEANUT in predicting vegetative growth.

Key Words: Peanut, *Arachis hypogaea* L., growth model, simulation, spanish.

Peanut (*Arachis hypogaea* L.) requires a relatively high level of management, and many production decisions have important economic consequences. A few examples are the selection of a cultivar, the timing of planting and harvesting, the scheduling of irrigations, and decisions related to disease and insect control. The potential exists to better quantify these decision making processes through the use of dynamic crop growth models. Properly validated models allow a more objective evaluation of alternative management practices by analyzing their effects on crop growth and yield. Crop models can also in some cases provide a viable alternative to, or at least supplement, expensive field experimentation. These important applications of peanut growth simulation suggest that work should continue on developing and adapting dynamic models which simulate growth, development, and yield of peanuts.

The development of peanut growth models has taken place primarily during the last 15 years. Duncan (3) described an early attempt at the dynamic modeling of peanut growth, but no further details were published. Young *et al.* (11) developed a comprehensive model which simulates all vegetative and reproductive processes of the peanut plant. Since publication of the original model, further work has been done on simulating root growth and modeling soil moisture (12). Ingram *et al.* (6) developed a very simple model designed to be used

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for educational purposes. This model takes into consideration only the effects of temperature and solar radiation on crop growth and assumes that all other production factors are non-limiting for peanut growth. A general growth model for all crops is part of an overall farming impact model described by Williams *et al.* (10). In this model, plant growth and its effect on soil productivity and soil erosion are simulated. Boote *et al.* (1,2) recently modified a soybean growth model to simulate the growth of Florunner peanut. This too is a comprehensive model which considers balances of carbon, nitrogen, and soil water.

In this study, the models of Ingram *et al.* (6) and Young *et al.* (11,12) were examined as potential tools for simulating the growth of spanish peanut in Oklahoma. These models, which vary greatly in complexity, will be referred to as PNUTMOD and PEANUT, respectively. Field data from several sites were utilized in adapting and calibrating the models for Oklahoma conditions.

Materials and Methods

Site Descriptions - Field data were collected from four sites in Caddo County, Oklahoma, during the 1985 growing season. These sites were within large irrigated fields of private cooperators. To be consistent with a companion project in the area, the four sites were designated as 4A, 6B, 9A, and 10A. On each of the sites, the "Spanco" spanish type peanut cultivar was grown with a row spacing of 0.91 m. Presented in Table 1 for each site are the soil type according to the USDA-SCS Soil Survey (9), the plant density within the row, and the dates of planting, emergence, and final yield sampling. Plant density was determined at the time final yield samples were taken. The cooperators followed their normal irrigation practices, and among the four sites, total growing season rainfall/irrigation amounts varied by a factor of two (Table 2). Irrigation water was applied with a side-roll sprinkler system on site 10A and with center pivot systems on the other three sites. Leafspot slightly affected site 6B and caused abnormal leaf abscission and an early physiological maturity at site 10 A.

Table 1. Information on the four study sites.

Site No.	Soil Type	Plants per m of Row	Planting Date	Emergence Date	Final Sample Date
4A	Hollister silt loam (fine, mixed, thermic, pachic paleustoll)	16.8	May 25	May 31	Sept. 28
6B	Cobb fine sandy loam (fine-loamy, mixed, thermic, udic haplustalf)	10.7	May 23	May 29	Sept. 28
9A	Dougherty loamy fine sand (loamy, mixed, thermic, arenic haplustalf)	9.8	June 13	June 18	Oct. 1
10A	Dougherty loamy fine sand (see above)	16.0	May 28	June 3	Sept. 21

Table 2. Monthly rainfall/irrigation amounts (mm) from planting date through final sample date for the four study sites.

Month	Site 4A	Site 6B	Site 9A	Site 10A
May	13	13	--	0
June	197	185	19	190
July	180	165	69	112
August	227	121	117	182
September	195	163	203*	53
Total	812	647	408	537

* Includes a rainfall of 88 mm that occurred two days before the final sample date.

Weather - A microprocessor-based weather station (Campbell Scientific, Inc.) was set up at the Caddo Research Station (35°10' N, 98°30' W), which is within 12 km of all four study sites. The weather station's datalogger computed hourly and daily summaries of wet and dry bulb temperature, solar radiation, and wind speed and direction. These data were transmitted each day via telephone line to an IBM-PC-XT microcomputer located in the offices of the Caddo Electric Cooperative.

Rainfall and irrigation data were collected at each site using two rain gauges mounted just above the crop canopy. The rain gauges were read when soil moisture readings were taken (every two to three days). A small amount of cooking oil was added to the gauges to suppress evaporation between readings.

Soil Moisture - Two neutron probe access tubes were installed at each site to a depth of 1.37 m. The tubes were located about 3 m apart in a peanut row in a uniform area representative of the surrounding field. Neutron readings of soil moisture (Model 3333 Moisture Gauge, Troxler Electronic Laboratories, Inc.) were made at 0.15 m intervals to a depth of 1.2 m. Moisture data were taken every two to three days throughout the growing season. Values for the soil field capacity and wilting point were needed in order to estimate available soil moisture. At each site, field capacity was estimated from neutron probe readings taken after a large rainfall event early in the growing season. The wilting point (15 bars of tension) was estimated from field data and the work of Rawls *et al.* (8).

Yield Samples - Whole plant samples were taken throughout the growing season at intervals of about five days. A sample was taken within about a 10 m radius from the neutron access tubes and no closer than 2 m from a previous sampling site. The sampling location was visually chosen based on being uniform and representative of the surrounding field. All plants within a 0.60 m section of row were removed. A larger sample would have been more desirable statistically but would have resulted in excessive field damage. For the final yield determination, four of the 0.6 m row sections were taken for replication.

The plant samples were air dried and then processed by separating the pods and vegetative canopy parts and removing surface dirt. Following the suggestions of Young *et al.* (13), the pods were oven dried at 130 C for six h and then weighed. The air dried vegetation samples were crushed, oven dried at 70 C for six h, and then weighed. Data for both the pods and vegetation were converted to a mass per unit area basis.

Pod Analysis - The pods from the four replicate samples of final yield were counted and averaged to obtain a total pod count. In addition, approximately 20 of the largest, completely filled pods were selected, dried, and weighed, with the average mass providing an estimate of maximum pod mass. About 20 of the smallest acceptable pods were also selected, dried, weighed, and an average taken to estimate the minimum acceptable pod size.

Description of PNUTMOD - The peanut growth model presented by Ingram *et al.* (6) is a simple simulation model developed for a hand calculator. The model predicts vegetative canopy mass and pod mass on a per unit area basis. Crop phenology is assumed to be a function of temperature, while dry matter accumulation is a function of solar radiation. PNUTMOD divides the growing season into three phases: expansion, pod set, and pod fill. In addition to temperature and radiation data, the model requires seven varietal input parameters. The model assumes that fertility, weeds, disease, and soil water are not limiting growth. PNUTMOD was programmed in BASIC and executed on an IBM-PC microcomputer.

The original model was altered in two ways for this study. First, a problem with premature termination of the pod set phase was corrected. Because of one of the empirical relationships used in PNUTMOD, an abnormally low radiation day (below approximately 12 MJ/m^2) was found to terminate pod set abnormally early. Thus the model's check for completion of the pod set phase was skipped whenever daily solar radiation totaled less than 12 MJ/m^2.

Secondly, a simple soil moisture factor was added to the model based on the assumption that a moisture deficit would limit the amount of daily assimilate. The soil moisture factor, which can assume values between 0 and 1, is dependent only on the percent of available soil water and is identical in form to the factor often used to adjust estimates of evapotranspiration when soil moisture is limiting (7). After this modification to the model, soil moisture stress has the effect of reducing vegetative mass throughout the season and reducing pod mass during the fill phase.

Description of PEANUT - The model of Young *et al.* (11,12), called PEANUT, is much more comprehensive than PNUTMOD. PEANUT consists of a set of FORTRAN subroutines which simulate such processes as: emergence; photosynthate production; respiration; initiation and number of flowers, pegs, and pods; soil water balance; root growth; peg strength; and leaf abscission. No attempt will be made here to describe the individual components of Young's overall model. Details may be found in Young *et al.* (11) and Grosz (5).

Some relatively minor modifications were made to PEANUT prior to the calibration process. An option for modeling disease loss was eliminated because of a lack of data necessary for its execution. A soils subroutine was altered in order to better describe the soils at the four study sites. The model subroutines were compiled, linked, and executed on an IBM-PC microcomputer.

Results and Discussion

Yield Samples - Results from the analysis of sequential plant samples are presented in Table 3. Pod yields of course increased as the season progressed, but not necessarily in a monotonic fashion due to the random nature of plant sampling. Although a large number of samples were taken throughout the growing season, replicated samples on each sampling date would perhaps have been more desirable. Vegetative samples exhibited more variability than the pod samples, and leaf senescence was a factor in the latter part of the growing season. Pod yields were highest for the more fully irrigated sites (4A and 6B).

Table 3. Sequential yield data (g/m^2) for the four study sites.

Date	Calendar Day	Site 4A Pod	Site 4A Veg.	Site 6B Pod	Site 6B Veg.	Site 9A Pod	Site 9A Veg.	Site 10A Pod	Site 10A Veg.
Jul 5	186	-	88	-	108	-	27	-	82
16	197	7	222			-	95	14	213
19	200			20	276				
22	203	15	274			-	141	22	222
24	205			27	263				
26	207	18	348			-	131	54	269
29	210			78	410				
31	212	54	-			6	205	69	351
Aug 6	218	128	492	118	530	22	278	111	-
12	224	184	432	278	-	43	360	184	348
19	231	274	-	254	488	80	371	238	415
23	235	284	493	444	447	120	538	213	282
27	239	398	538	325	458	108	566	250	378
31	243	359	613	371	557	144	553	334	462
Sep 3	246	442	532	375	427	269	561	475	468
7	250	607	667	445	478	220	528		
10	253	512	625	466	484	188	463	496	362
14	257	540	500	286	357	268	455		
17	260	580	583	456	405	245	486	460	392
21	264*							438 (62)	362 (35)
24	267	518	487	722	590	343	451		
28	271*	593 (69)	554 (78)	527 (87)	426 (49)				
Oct 1	274*					295 (51)	443 (24)		

* Final yield data represent the mean of four replicate samples, with standard deviations given in parentheses.

Pod Analysis - Table 4 provides a summary of the analysis of pods from the final yield samples. The pod count was highest for site 4A, which had a high plant density. Site 10A had about the same plant population as site 4A but its pod count was the lowest of the four sites, probably due to the combined effects of insufficient irrigation water and disease damage. However the largest pods were found at this site. Both the maximum pod mass and minimum harvestable pod mass were smallest for site 9A, which was planted two to three weeks later than the other sites and also was marginally irrigated.

PNUTMOD - To calibrate the revised version of PNUTMOD for Oklahoma conditions, various combinations of the seven model parameters (Table 5) were tested iteratively, using input data for sites 4A and 9A. These sites were selected because they received the most and least irrigation water of the study sites, and because they were nearly disease free. Optimum parameter values for each of the two sites were found using a least squares criterion for both vegetative mass and pod mass. The two sets of optimum parameters (one for each site) were compared and found to be similar. Further testing was done until a single "best fit" parameter set was obtained (Table 5). This parameter set was then used in simulating peanut growth at the remaining two sites, 6B and 10A (Fig. 1).

Table 4. Analysis of pods from the final yield samples.

Site	Pod Count (pods/m^2)	Maximum Pod Mass (g)	Minimum Pod Mass (g)
4A	760	1.30	0.50
6B	680	1.32	0.48
9A	600	1.17	0.36
10A	490	1.42	0.61

Table 5. Optimum parameter set for PNUTMOD simulations.

Parameter Name	Description*	Value
DUE	Total daily developmental units required for expansion phenophase (10 C base temperature)	640 C
EXP	Exponent in equation for ground cover fraction	3.5
PART	Maximum fraction of daily assimilate partitioned to pod growth	0.96
PCF	Pod composition factor	0.62
PNE	Photosynthetic efficiency	0.92 g veg. dry matter/MJ
PSF	Pod set factor	$0.0196\ g/m^2 \cdot C$
PWF	Pod weight factor	1.85 g

* See Ref. 5 for more detailed parameter descriptions.

As shown in Fig. 1, the simulated vegetative growth was consistently higher than that observed in the field. These plots illustrate that, in PNUTMOD, vegetative mass increases slowly but steadily during pod fill. This response is contrary to that reported by Duncan *et al.* (4). The model simulations of pod growth agreed quite well with the independent field observations at sites 6B and 10A. Since pods provide the economic return, accurate estimates of pod yield are generally of greater benefit than are estimates of vegetative growth.

PEANUT - PEANUT was originally developed for the virginia type peanut grown in North Carolina. Therefore, to begin the calibration process, the 65 parameters in the model were examined in an attempt to identify those which might need to be changed for the spanish type peanut grown in Oklahoma. Eleven parameters were so identified, with nine of those eventually being modified as a result of the calibration process. A summary of this calibration process follows.

First of all, based on the analysis of final yield samples, a value of 0.50 g was selected for the minimum harvestable pod mass. The analysis also showed that the mature spanish pod had a mass approximately half that of a virginia type pod. Since the length of the pod maturation phase of peanut growth is similar for both

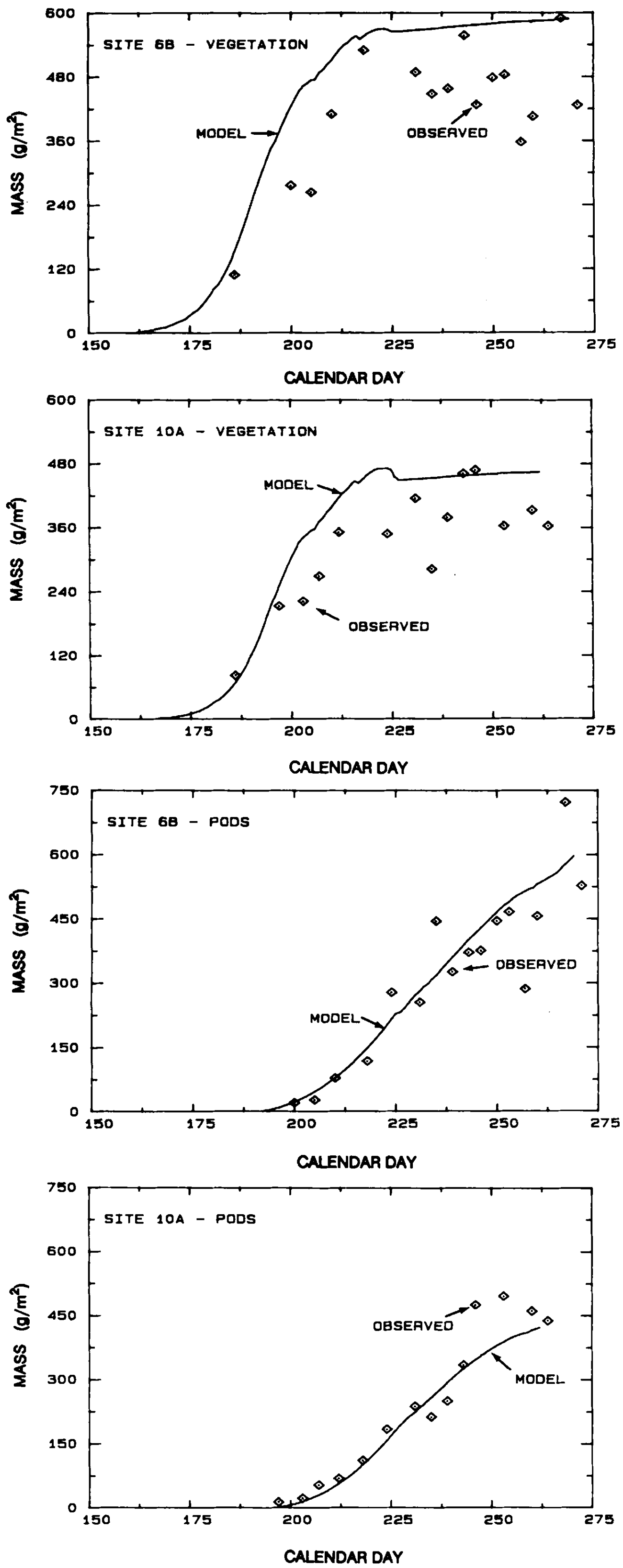

Fig. 1. PNUTMOD simulations and field observations of vegetative and pod mass for sites 6B and 10A.

peanut types, initially the maximum pod fill rate in the model was reduced by about one-half.

The model's predicted time of plant emergence is a function of the summation of daily average temperatures. The parameter which sets the threshold level for emergence was adjusted until the model predicted the actual emergence dates for the four study sites. Observed total biomass production was used as the criterion for adjusting a varietal parameter which relates total photosynthate production to the mass of photosynthetically active plant tissue. The model's threshold growth rate for flowering was decreased until the early pod mass predictions agreed with field data.

Another of the model parameters sets the quantity of photosynthate required to initiate new pods. This parameter and the maximum pod fill rate were adjusted so that predicted pod yields approximated the sequential yields observed in the field. After the values of these parameters were set, the ratio of pod mature weight to pod weight 28 days after initiation was modified so as to agree with the measured data on maximum pod mass.

In summary then, values of the following model parameters were modified as a result of the calibration process for the spanish type peanut: the minimum harvestable pod mass, an emergence constant, a parameter relating photosynthate production to the mass of active plant tissue, the threshold growth rate for flowering, the photosynthate needed to initiate new pods, the ratio of pod mature weight to pod weight 28 days after initiation, and three parameters in an empirical equation for determining pod fill rate. Two other identified growth parameters, the maximum fraction of photosynthate deficiency that can be supplied from storage and a constant in the equation for determining the number of flowers set, were not changed because of a lack of information for making any modification in their values.

In Fig. 2 and 3, model simulations of vegetation and pod growth are compared to field data from the four sites. Since data from all four sites were used in the calibration process, these plots do not represent an independent check of the model. Given the size of the field data set and the fact that PEANUT is a complex model with a large number of parameters, it was decided to use all available data in calibrating the model. It should be pointed out that the same parameter set was used for all four sites.

As was the case with the PNUTMOD simulations, the agreement between PEANUT model predictions and field data was generally better for pod yields than for vegetative yields. The model simulated vegetative growth fairly well for sites 6B and 9A, but over-predicted the vegetative mass at sites 4A and 10A. Some abnormal leaf loss occurred at site 10A due to leafspot disease. Also, sites 4A and 10A had much higher plant densities (Table 1), and the poor agreement may indicate a problem with the shading factor in PEANUT. The pod growth simulations matched the field data quite well during the early part of the growing season and then began to deviate more as the crop matured. However this was also the period when the sample pod yields exhibited greater variability.

Conclusions

Both models, as calibrated for spanish peanut in

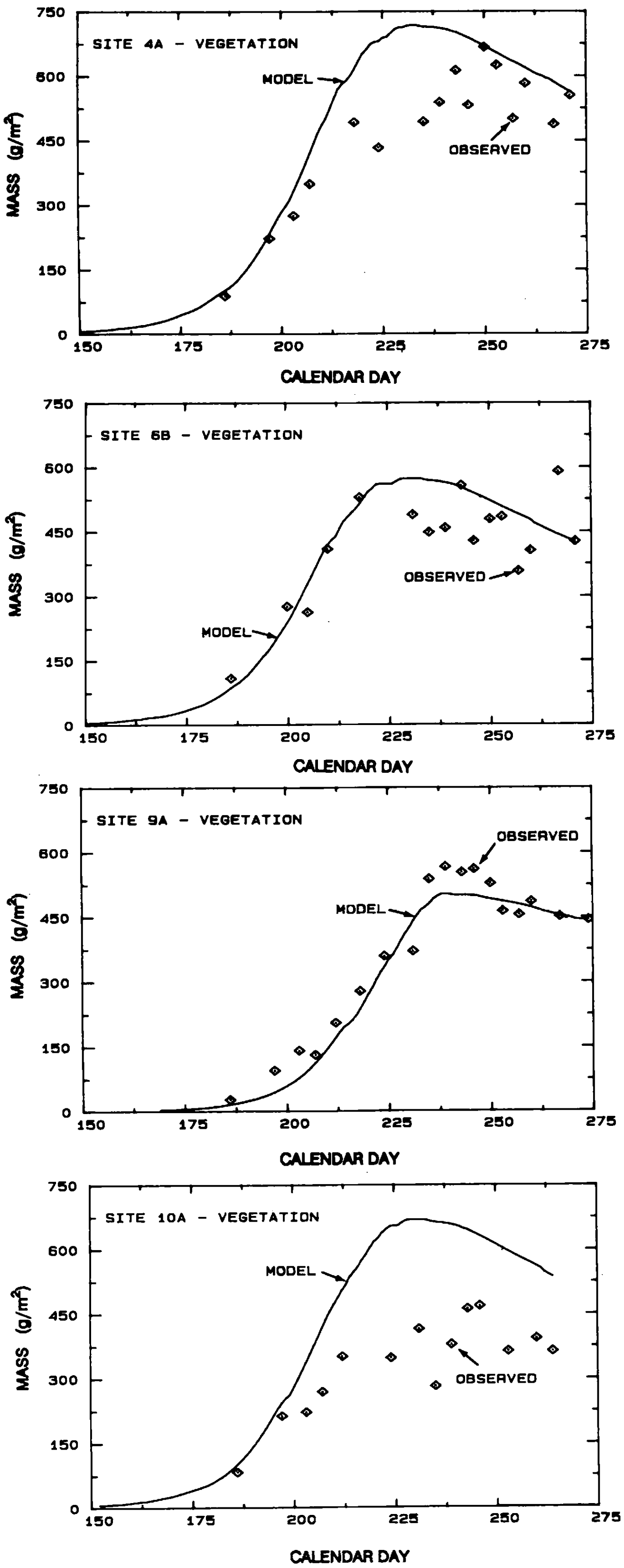

Fig. 2. PEANUT simulations and field observations of vegetative mass for the four study sites.

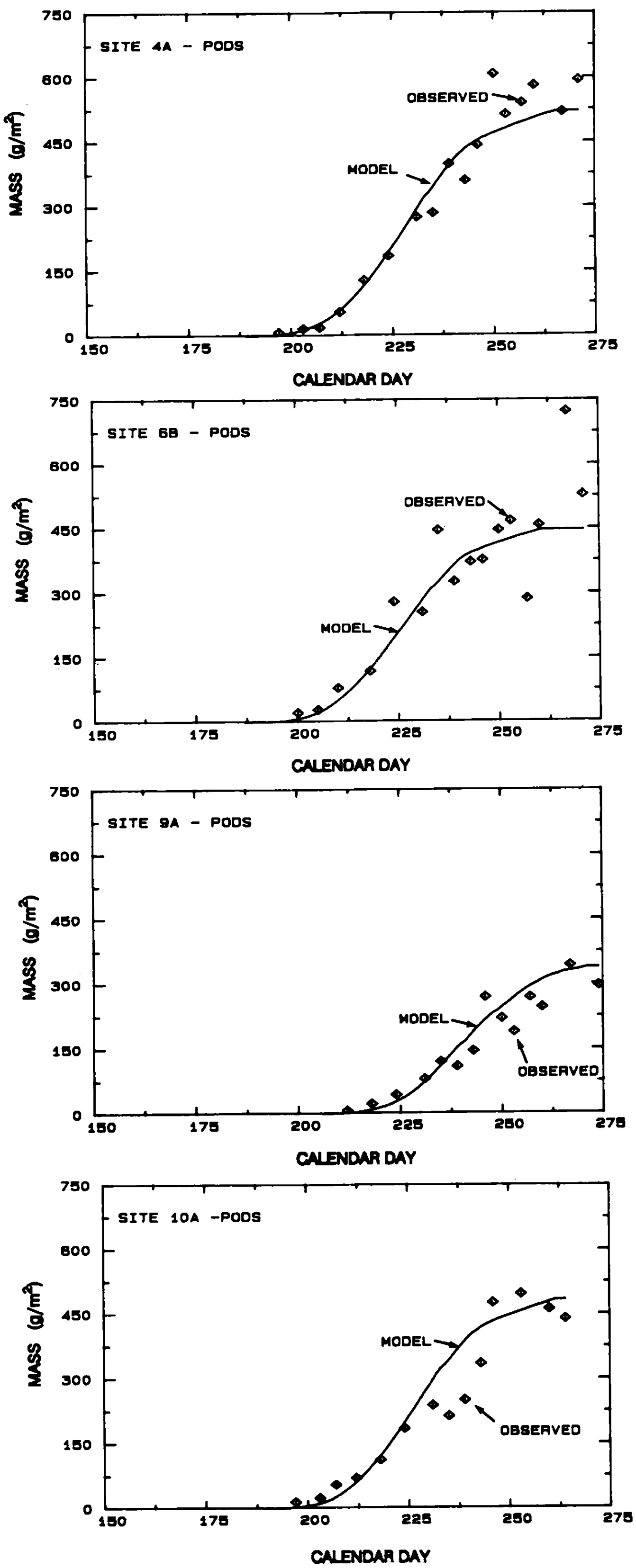

Fig. 3. PEANUT simulations and field observations of pod mass for the four study sites.

Oklahoma, simulated pod yield very well. Simulation of vegetative growth was adequate, but PEANUT is physiologically more correct because of the senescence of vegetation late in the season. Better data sets would be beneficial in future modeling efforts related to spanish peanut. Work should continue on developing, improving, and adapting peanut growth simulation models.

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