Peanut Science (1979) 6, 27-36

A Peanut Growth and Development Model[1]

J. H. Young,* F. R. Cox, and C. K. Martin[2]

ABSTRACT

A first generation FORTRAN computer program has been developed to simulate the growth and development of peanuts from the date of planting until harvest. Top growth, flowering, pegging, and fruiting are simulated by the program. Required inputs are daily values for maximum and minimum temperatures, radiation, and soil moisture level. Preliminary evaluations of the model have been made using growth data collected during 1974 and 1975 for the Florigiant and Florunner cultivars. A number of areas have been identified for further research to improve our understanding of peanut growth and development and to evaluate hypotheses included in the current model.

Key Words: Peanut, Growth, Model, Photosynthesis, Flowering, Pegging, Respiration.

As with all agricultural commodities, peanuts are produced in anticipation of a profit. There are many factors in the production cycle which determine the magnitude of either a profit or a loss. Although, considerable information has been gathered on many of these factors, there has been little effort to pool such data in a mathematical expression or model which can be used in making management decisions to optimize profit.

For certain portions of the peanut production cycle models have been developed or are underway. Whitaker and Young (1972), Chhinnan and Young (1976a and 1976b), Emery, et al. (1969), Cox and Martin (1974), Mills (1964) and Shear and Miller (1959) have attempted to relate the development of the peanut plant to temperature with special attention directed toward predicting the time of flowering and the optimum harvest time. Duncan (1974 and 1975) has discussed the use of a model for predicting growth, development, and yield of peanut plants though details of his model have not been published.

There is much about the growth of the peanut plant that we do not know. This quickly becomes apparent when an attempt is made to mathematically describe the growth. Modeling attempts thus help to identify those gaps in our knowledge toward which we should devote more of our research efforts. As pointed out by Bowen et al. (1973), one of the first benefits of crop simulation will often be in the form of increased research efficiency. When we understand the growth process, development of a mathematical description of that process is relatively simple.

[1]Paper Number 5437 of the Journal Series of the North Carolina Agricultural Experiment Station, Raleigh, N. C.

[2]Professor, Biological and Agricultural Engineering; Professor, Soil Science; and Assistant Professor, Soil Science, respectively of the North Carolina State University, Raleigh, N. C.

The model to be described here is not the ultimate peanut growth model. Model development is an iterative process in which known information and hypotheses concerning basic growth processes are combined to give mathematical predictions of plant behavior under various conditions. Model prediction and experimental results must then be compared for validation and/or refinement of the model. The objectives of this publication are: (1) to outline a first generation model for simulating the growth of the peanut plant from planting to harvest, and (2) to evaluate parameter values which give the best representations of experimental field data for the 1974 and 1975 crops at Lewiston, N. C.

MODEL DESCRIPTION

Figure 1 is a simplified flow chart of the peanut growth model. It begins by simulating the time of emergence of the plants and then, for each day of the growth cycle, it simulates the photosynthate produced, the maintenance respiration, the change in pod mass, the change in pod number, the change in peg mass, the change in peg number, the flower count, and the change in leaf and stem mass. Growth respiration for each plant part is predicted within blocks simulating growth of that part. Mathematical expressions used in each of these predictions are given in sections (a) through (k) which follow.

(a) Emergence

The time of emergence is predicted as a function of the daily maximum and minimum temperatures using a procedure developed by Cox and Martin (1974) for the prediction of time to flowering. Emergence is assumed to occur on the first day for which the function, F of equation (1), exceeds a predetermined level, p(1). Thus, emergence occurs when:

$$F = 0.5 \sum_{i=1}^{I} (YMAX_i + YMIN_i) \geq p(1) \qquad (1)$$

where
i = day count from date of planting (date of planting is day 1);
I = day i on which emergence occurs;
$YMAX_i$ = function of maximum temperature for day i, dimensionless;
$YMIN_i$ = function of minimum temperature for day i, dimensionless;
p(1) = value of F at which emergence occurs.
$YMAX_i$ and $YMIN_i$ are computed daily using equations given by Cox and Martin (1974).
On the day of emergence, the peanut plant is assigned a total top mass of p(2) grams.

(b) Photosynthate Production

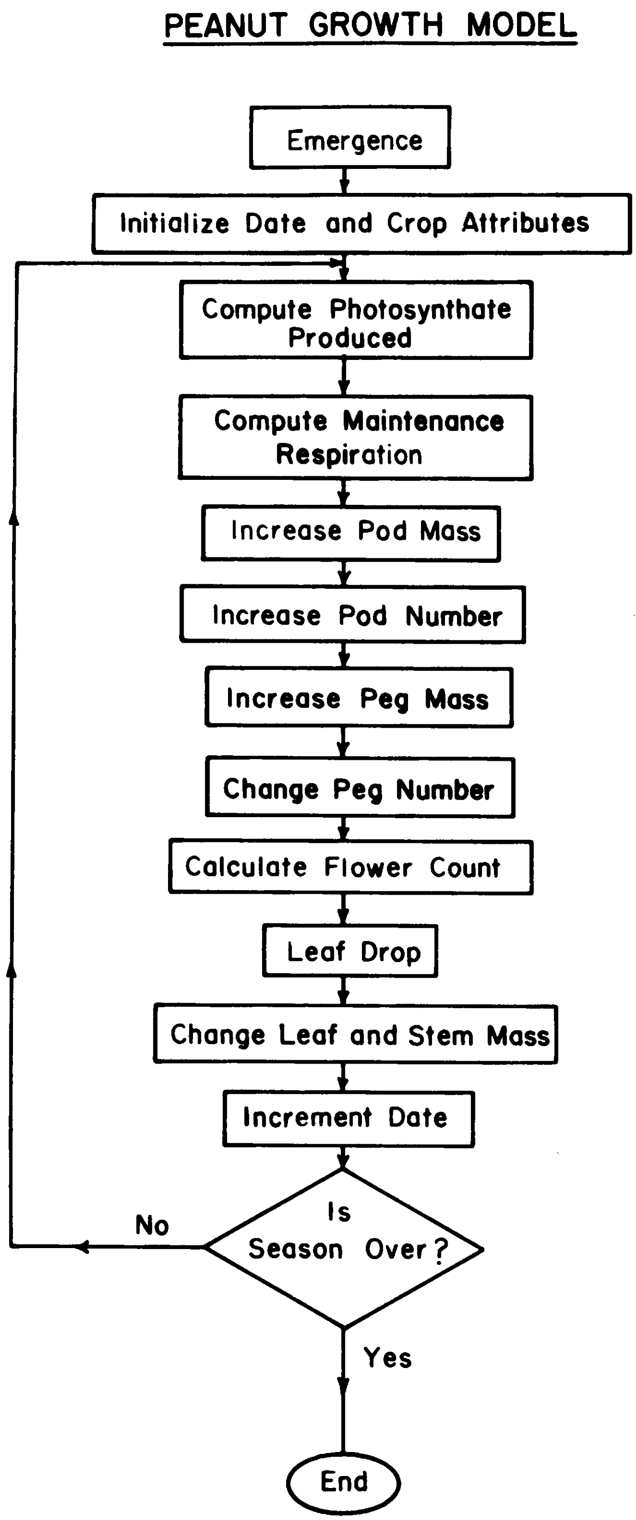

Figure 1. Schematic of peanut growth model.

After emergence, the production of photosynthate is calculated during each day of the season in a manner similar to that used by Rickman et al. (1975):

$$CFIXED = K * W \qquad (2)$$

where
CFIXED = total photosynthate (gross-photorespiration) produced during the day per unit area, gm/m^2 day;
K = daily growth parameter, day^{-1}
W = mass of photosynthetically active plant tissue per unit area, gm/m^2.

Equation (2) assumes that the photosynthate production during a day is proportional to the photosynthetically active leaf mass whereas Rickman et al. (1975) assumed that the dry matter accumulation per day was proportional to the dry matter present. Either of these assumptions involve the additional hypothesis that leaf area is directly proportional to leaf mass.

The mass of photosynthetically active plant tissue, W, is the mass of leaves corrected for loss in photosynthetic ability due to age. Leaf material developed on a given day is aged in a linear fashion based on the photosynthetic efficiency observations of Gallaher et al. (1976) and Henning et al. (1975):

$$W = ILW[1.0-p(12)*(AGE-p(11))] \qquad (3)$$

where
ILW = initial leaf mass per unit area, gm/m^2;
AGE = chronological age of leaf, days;
p(11) = age at which leaf begins to lose photosynthetic ability, days;
p(12) = rate of loss of photosynthetically effective leaf mass, day^{-1}.

The growth parameter, K, is a function of a number of environmental factors as discussed by Rickman, et al. (1975). The relationship assumed in this model is:

$$K = p(10) * TF * RF * MF * SF \qquad (4)$$

where
p(10) = constant for the peanut variety, day^{-1};
TF = temperature factor, dimensionless;
RF = radiation factor, dimensionless;
MF = soil moisture factor, dimensionless;
and SF = shade factor, dimensionless.
The temperature factor, TF, accounts for the effect of temperature on the photosynthetic rate. Based on the relative growth rate observations of deWit (1970), the following equation form was assumed:

$$TF = 1/\exp\left[\frac{p(3) - T_{av}}{p(4)}\right]^2 \qquad (5)$$

where
T_{av} = average of the daily maximum and minimum temperature, K;
p(3) = optimum temperature for photosynthesis, K;
p(4) = constant, K.

The radiation factor, RF, accounts for the effect of radiation level on the photosynthetic rate of individual leaves. It was assumed to be of the form shown by Meyer, et al. (1960) for the effect of light intensity on photosynthetic rate. This relationship may be approximated by the following exponential relationship:

$$RF = 1.0 - \exp[-p(5)*R] \qquad (6)$$

where
R = total radiation (wavelengths, 280-2800 nm) for day, MJ/m^2
p(5) = constant, m^2/MJ.

The soil moisture factor, MF, was expected to be a non-linear function. However, rather than basing the relationship on percent available water as used by Jensen et al. (1970), the following relationship based on soil moisture tension was assumed:

$$MF = \sqrt{1.0 - \left(\frac{M}{p(6)}\right)^{p(7)}} \quad (7)$$

where
M = soil moisture tension, MPa
p(6) = soil moisture tension at which photosynthesis ceases, MPa
p(7) = constant, dimensionless.

Shading should be of no consequence until sufficient leaf mass has accumulated to compete for incoming radiation. Thus the shading factor, SF, is:

$$SF = 1.0 \text{ if } X < p(8) \quad (8)$$

where
X = mass of leaves per unit land area, gm/m^2
p(8) = leaf density at which shading becomes important, gm/m^2.

At leaf densities greater than p(8) the shading factor was assumed to decrease hyperbolically as follows:

$$SF = \frac{p(8)+p(9)}{X+p(9)} \quad \text{if } X \geq p(8) \quad (9)$$

where
p(9) = constant, gm/m^2.

(c) Maintenance Respiration

The net amount of photosynthate available for plant growth during a particular day (CFIXN) is less than the total photosynthate produced (CFIXED) by an amount which is required to maintain the existing plant mass. This maintenance respiration rate is predicted by an Arrhenius equation as used by Waggoner (1969):

$$RESP = p(14) * TWT * \exp\left[p(15) * \left(\frac{1}{293} - \frac{1}{T_{av}}\right)\right] \quad (10)$$

where
RESP = daily maintenance respiration per unit area, gm/m^2;
p(14) = respiration rate at 293 K, dimensionless;
TWT = total mass of plant per unit area, gm/m^2;
p(15) = parameter to account for effect of temperature on respiration rate, K;
T_{av} = average of daily maximum and minimum temperatures, K.

(d) Photosynthate Storage

A portion of the mass of leaves and stems is assumed to be a pool of photosynthate for use when conditions are such that daily net photosynthate production falls below a threshold level. This pool becomes available when:

$$FRCFIX = CFIXN/W < p(13) \quad (11)$$

where
FRCFIX = ratio of net photosynthate produced during a day to the mass of photosynthetically active tissue, dimensionless;
CFIXN = net photosynthate produced during a day per unit area, gm/m^2;
W = mass of photosynthetically active plant tissue per unit area, gm/m^2;
p(13) = threshold level of ratio which triggers removal of mass from pool, dimensionless.

When removal of mass from the pool is triggered on a given day, the following fraction of the leaf and stem mass is added to the photosynthate available for distribution and leaf and stem masses are reduced accordingly:

$$FRPOOL = (p(13) - FRCFIX) * W/TOP \quad (12)$$

where
FRPOOL = fraction of leaf and stem mass which is reconverted to photosynthate and made available for distribution, dimensionless;
TOP = total mass of leaves and stems per unit area, gm/m^2.

At present, there is no limit in the model on the fraction of the leaf and stem mass which can be drawn upon in periods of photosynthate deficiency. This needs further study and model revision. However, in actual implementation of the model, leaf drop (described in section j) is triggered prior to removal of large quantities of the leaf and stem mass.

(e) Change in Pod Mass

Once the amount of photosynthate available for distribution has been determined for a particular day, the developing pods are given first priority for that photosynthate. If there is sufficient photosynthate, the daily change in mass of the developing pods was found by Schenk (1961) to be essentially constant. Thus, the following relationship:

$$\Delta WP = N_{pods} * p(16) \quad (13)$$

where
ΔWP = total daily change in mass of developing pods per unit area, gm/m^2;
N_{pods} = number of developing pods on the peanut plants per unit area, $\#/m^2$;
p(16) = daily limit on photosynthate used for growth of an individual pod, gm.

If the available photosynthate is insufficient to provide the maximum growth rate for all developing pods, the available photosynthate is distributed among the pods equally leaving no reserve for growth of other plant parts. The relationship for growth of each individual pod in this case is:

$$\Delta WPI = \frac{CAVAIL}{p(18) * N_{pods}} \quad (14)$$

where
ΔWPI = daily change in mass of each pod, gm
CAVAIL = photosynthate available for distribution per unit area, gm/m^2;
p(18) = 1.0 + pod growth respiration factor, dimensionless;
N_{pods} = number of developing pods on the peanut plant per unit area, $\#/m^2$.

(f) Change in Number of Developing Pods

After distributing photosynthate among the developing pods on a given day, the number of pods is adjusted to account for the maturation of some pods which will require no more photosynthate for growth and the initiation of new pods during the day. If an individual pod has reached a maximum mass, p(19), it is considered to be mature and the number of such pods is subtracted from the number of developing pods. If there is still photosynthate available after growth of the developing pods, new pods may be initiated if there are available pegs of sufficient size. The number of new pods initiated in a given day is predicted by:

$$\Delta N_{pods} = \min\left[N_{ap}, \frac{CAVAIL}{p(17)}\right] \qquad (15)$$

where
ΔN_{pods} = number of new pods initiated on the day per unit area, #/m^2;
N_{ap} = number of "mature" pegs per unit area, #/m^2;
CAVAIL = photosynthate available after distribution to pods, gm/m^2;
p(17) = quantity of available photosynthate per unit area required to trigger pod initiation, gm/m^2.

(g) Change in Mass of Pegs

Growth of developing pegs has next priority for the photosynthate to be distributed. If there is sufficient photosynthate, the change in the mass of developing pegs is determined by:

$$\Delta WPG = N_{pegs} * p(21) \qquad (16)$$

where
ΔWPG = total daily change in mass per unit area of developing pegs, gm/m^2;
N_{pegs} = number of developing pegs per unit area on the peanut plants, #/m^2;
p(21) = daily limit on photosynthate used for growth of an individual peg, gm.

If the available photosynthate is insufficient to provide the maximum growth rate for all developing pegs, the available photosynthate is equally distributed among the pegs. The relationship for growth of individual pegs in this case is:

$$\Delta WPGI = \frac{CAVAIL}{p(22) * N_{pegs}} \qquad (17)$$

where
$\Delta WPGI$ = daily change in mass of each peg, gm;
CAVAIL = photosynthate still available for distribution per unit area, gm/m^2;
p(22) = 1.0 + peg growth respiration factor, dimensionless;
N_{pegs} = number of developing pegs per unit area, #/m^2.

(h) Change in Number of Developing Pegs

After distributing photosynthate among the developing pegs on a given day, the number of pegs is adjusted to account for the "maturation" of some pegs which will require no more photosynthate, the death of some pegs due to dry soil, and the initiation of new pegs during the day. If an individual peg has reached a mass, p(23), it is considered to be "mature" and the number of such pegs is subtracted from the number of developing pegs and added to the number of "mature" pegs. These "mature" pegs are made available for pod initiation if photosynthate is available prior to the peg reaching a maximum age of p(24) days. The number of developing pegs may also be reduced by dry soil conditons on the seventh day after peg initiation. This is predicted by the relationship:

$$PEGCT(J\text{-}7) = PEGCT(J\text{-}7) * XMFPEG \qquad (18)$$

where
PEGCT(J-7) = number of developing pegs which were initiated on day (J-7), #/m;
and XMFPEG = soil moisture factor for peg development, dimensionless.

The soil moisture factor for peg development on a given day is similar to the soil moisture factor for photosynthesis and is given by:

$$XMFPEG = 1.0 - \left(\frac{M}{p(26)}\right)^{p(27)} \qquad (19)$$

where
M = soil moisture tension, MPa
p(26) = soil moisture tension at which pegs are killed, MPa;
p(27) = constant, dimensionless.

If there is still photosynthate available after growth of the developing pegs, new pegs may be initiated if there are available flower sites. The number of available flower sites is the flower count for the previous day. The number of pegs initiated on a day is then predicted by:

$$\Delta N_{pegs} = \min\left[FC(J-1), \frac{CAVAIL}{p(25)}\right] \qquad (20)$$

where
ΔN_{pegs} = number of new pegs initiated per unit area on the day, #/m^2;
FC(J-1) = flower count per unit area for the previous day, #/m^2;
CAVAIL = photosynthate per unit area available after distribution to developing pegs, gm/m^2;
p(25) = quantity of available photosynthate per unit area required to trigger peg initiation, gm/m^2.

(i) Flower Count

The flowering rate for the day is predicted as a function of environmental factors for the day and the rate of top growth three days earlier. The three day time interval was chosen based on the work of Nicholaides et al. (1969). If the top increase three days earlier is less than p(28) there is no flowering for the day.

Otherwise,

$$FC(J) = TOPINC(J\text{-}3) * p(29) * RFFLR * TFFLR * XMFFLR \qquad (21)$$

where
FC(J) — flower count for day J, #/m
TOPINC(J-3) = increase of top mass per unit area on

day (J-3), gm/m^2;
p(29) - constant, #/gm;
RFFLR = flowering radiation factor, dimensionless;
TFFLR = flowering temperature factor, dimensionless;
XMFFLR = flowering soil moisture factor, dimensionless.

The factors TFFLR, RFFLR, and XMFFLR were determined by relationships analogous to equations (5), (6), and (19) respectively with parameters p(35), p(36), p(20), p(37) and p(38) substituted for parameters p(3), p(4), p(5), p(26), and p(27) respectively.

(j) Leaf Drop

If the ratio of photosynthate produced during a day to the mass of photosynthetically active tissue, FRCFIX (Eq. 11), drops below a predetermined level, p(30), a stress condition is triggered in which leaves are lost from the plant. The oldest leaves are lost first and the total mass of leaves lost during the day is:

$$DROPLF = TLFWT * (p(30) - FRCFIX) * p(31)) \quad (22)$$

where
DROPLF = mass of leaves lost during the day per unit area, gm/m^2;
TLFWT = total mass of leaves per unit area, gm/m^2;
p(30) = threshold level of FRCFIX ratio which triggers leaf loss, dimensionless;
FRCFIX = ratio of net photosynthate produced during a day to the mass of photosynthetically active tissue, dimensionless;
p(31) = constant, dimensionless.

(k) Growth of Leaves and Stems

Photosynthate remaining after distributions to pods and pegs is used for leaf and stem growth as follows:

$$TOPINC(J) = CAVAIL/p(22) \quad (23)$$

where
TOPINC(J) = new growth of leaves and stems per unit area for day J, gm/m^2;
CAVAIL = available photosynthate per unit area, gm/m^2;
p(22) = 1.0 + growth respiration factor, dimensionless.

The new top growth is distributed among leaves and stems such that the following relationship holds:

$$RLFTOP = p(32) + p(33) * AGE + p(34) * (AGE)^2 \quad (24)$$

where
RLFTOP = ratio of leaf mass to top mass, dimensionless;
p(32) = constant, dimensionless;
p(33) = constant, day^{-1};
AGE = age of peanut plant, days;
p(34) = constant, day^{-2}.

THE COMPUTER PROGRAM

A FORTRAN computer program was written for the mathematical model. The program was developed such that peanut growth could be simulated when given a set of values for the parameters, p(j), and comparisons could be made between simulated and experimental values of top mass, pod mass, and flower count. A routine was also included such that the p(j) values could be varied in order to fit the experimental top mass, pod mass, and flower count data. A weighted sum of squares of the differences between simulated and experimental values was evaluated and minimized by the routine. The weighted sum of squares is given by:

$$SS = TOPFAC * \sum_{i=1}^{n_1} (STOPWT_i - ETOPWT_i)^2 + PODFAC * \sum_{i=1}^{n_2} (SPODWT_i - EPODWT_i)^2 + FLRFAC * \sum_{i=1}^{n_3} (SFLRCT_i - EFLRCT_i)^2 \quad (25)$$

where
SS = sum of squares, dimensionless;
TOPFAC = weighting factor for top mass, dimensionless;
PODFAC = weighting factor for pod mass, dimensionless;
FLRFAC = weighting factor for flower counts, dimensionless;
$STOPWT_i$ = simulated top mass per unit area for the ith observation, gm/m^2;
$ETOPWT_i$ = experimental top mass per unit area for ith observation, gm/m^2;
$SPODWT_i$ = simulated pod mass per unit area for ith observation, gm/m^2;
$EPODWT_i$ = experimental pod mass per unit area for ith observation, gm/m^2;
$SFLRCT_i$ = simulated flower count per unit area for ith observation, $\#/m^2$;
$EFLRCT_i$ = experimental flower count per unit area for ith observation, $\#/m^2$;
n_1 = number of top mass observations;
n_2 = number of pod mass observations;
n_3 = number of flower count observations.

The weighting factors were determined by the following equations:

$$TOPFAC = \frac{10000\, n_1}{\left(\sum_{i=1}^{n_1} ETOPWT_i\right)^2} \quad (26)$$

$$PODFAC = \frac{10000 n_2}{\left(\sum_{i=1}^{n_2} EPODWT_i\right)^2} \quad (27)$$

and

$$FLRFAC = \frac{10000\, n_3}{\left(\sum_{i=1}^{n_3} EFLRCT_i\right)^2} \quad (28)$$

where the number 10000 was simply a scale factor. The use of the above weighting factors provided for relatively equal weight of the three different measured quantities in the determination of the parameter values.

Other inputs to the computer program include daily values of maximum and minimum temperatures, radiation, and soil moisture content during the growing season. Planting information such as row spacing, spacing within the row, and planting date must also be provided to the computer simulation model. More details of the computer program may be obtained by contacting the authors.

Material and Methods

Field Procedure

During the 1974 and 1975 growing seasons, peanuts were planted on each of nine planting dates to obtain growth curves for crops exposed to different environmental conditions. The planting dates ranged from mid- April to the first of July. Each experimental plot consisted of six rows of peanuts approximately 20 meters in length. Three replications of each of two varieties (Florigiant and Florunner) were planted on each date.

Throughout the season samples of the experimental plots were hand harvested periodically for determination of the pod and top mass. Samples were obtained from an 0.91 m length of row. Also, flower counts were made periodically for a separate 3.05 m length of row.

Measurements of daily maximum and minimum temperatures and total radiation were made during the growing season. Also, soil moisture contents were periodically measured and a moisture model was used to predict daily soil moisture contents for each experimental plot.

Parameter Determination

The experimental crop data and weather data were then used by the computer program to determine the values of the parameters, p(j), which minimized the sum of squares of differences between simulated and experimental values.

Results and Discussion

Table 1 gives the values of the parameters, p(j), which were found to give the best fit of the experimental data for each of the two crop years and peanut varieties. Note that some of the parameters were fixed at values estimated by the authors based on information previously available. The other parameters were evaluated by fitting data for all nine planting dates simultaneously.

Figures 2-4 show the simulated curves for top weights and pod weights along with the experimental values for the first, fifth, and ninth plantings of Florigiants in 1974. Figures 5-7 show the simulated flower counts and experimental values for the same three plantings. Note that the parameters used for the simulations of Figures 2-7 are those which best fit all nine plantings simultaneously. Thus, fits of individual plantings are not necessarily the best that could have been achieved with the model.

Figures 8-11 illustrate the effects of temperature,

Table 1. Parameter values giving the best fit of experimental data for Florigiants and Florunners during 1974 and 1975 crop years.

PARAMETER NUMBER	PARAMETER TYPE*	FLORIGIANT 1974	FLORIGIANT 1975	FLORUNNER 1974	FLORUNNER 1975	AVERAGE
1	F	0.2	0.2	0.2	0.2	0.2
2	F	0.4	0.4	0.4	0.4	0.4
3	F	305.5	305.5	305.5	305.5	305.5
4	V	26.41	31.32	25.49	29.69	28.23
5	V	0.220	0.323	0.210	0.392	0.287
6	V	1.953	2.870	1.887	4.418	2.782
7	V	2.14	1.63	2.14	3.55	2.37
8	V	114.75	58.75	110.22	58.25	85.49
9	V	89.27	117.53	89.01	101.59	99.35
10	V	0.287	0.274	0.287	0.274	0.280
11	V	20.78	17.82	22.70	17.96	19.82
12	V	0.0137	0.0134	0.0139	0.0127	0.0134
13	V	0.105	0.104	0.110	0.093	0.103
14	V	0.0091	0.0103	0.0096	0.0106	0.0099
15	V	4274.9	6801.6	4531.8	6528.7	5534.2
16	V	0.0918	0.0485	0.0904	0.0532	0.0710
17	V	1.31	2.33	1.17	2.20	1.75
18	F	2.0	2.0	2.0	2.0	2.0
19	F	2.6	2.6	2.12	2.12	-
20	V	0.0042	0.0419	0.0048	0.0564	0.0268
21	V	0.0033	0.0040	0.0033	0.0043	0.0037
22	F	1.2	1.2	1.2	1.2	1.2
23	V	0.0257	0.0267	0.0253	0.0259	0.0259
24	V	11	12	14	11	12
25	V	1.41	0.84	1.31	1.00	1.14
26	V	0.644	0.640	0.631	0.469	0.596
27	V	8.72	5.77	8.75	6.95	7.55
28	V	2.65	2.68	2.57	2.53	2.61
29	V	4.32	3.42	4.45	2.93	3.78
30	V	0.0237	0.0220	0.0231	0.0197	0.0221
31	V	3.74	2.98	3.30 '	2.87	3.22
32	F	0.502	0.502	0.502	0.502	0.502
33	F	-0.576	-0.576	-0.576	-0.576	-0.576
34	F	-0.0108	-0.0108	-0.0108	-0.0108	-0.0108
35	F	298.0	298.0	298.0	298.0	298.0
36	V	19.49	47.05	17.45	63.35	36.83
37	V	2.833	3.237	2.935	5.860	3.716
38	V	0.959	0.346	0.988	0.692	0.746

* F = parameters whose values were fixed.

V = parameters whose values were adjusted to obtain best fit of experimental data.

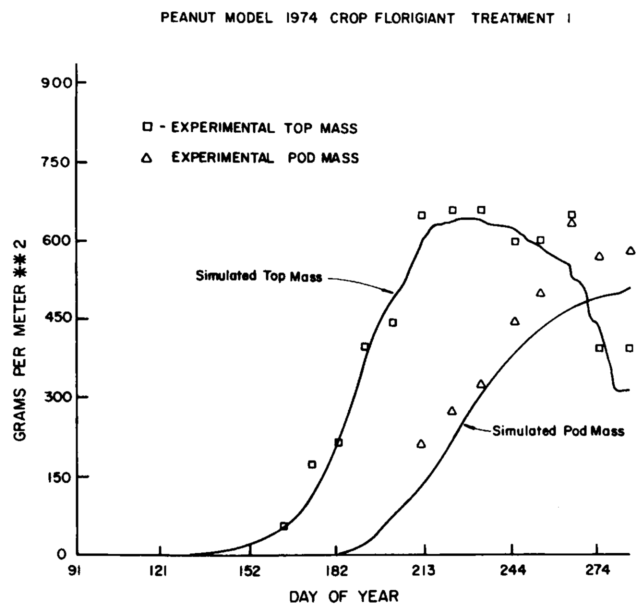

Fig. 2. Simulated and experimental top and pod growth curves for Florigiant peanuts planted on day 107 of 1974.

radiation, soil moisture, and shading respectively on photosynthate production. These figures show curves based on the average values (from Table 1) of the parameters p(3), p(4), p(5), p(6), p(7), p(8) and p(9) and also give curves based on the extreme values. Figure 8 indicates an optimum temperature of 305.5°K for photosynthate production and reduced rates at lower or higher temperatures. The range of temperatures over which TF is significant in Figure 8 is greater than had been expected and further tests under con-

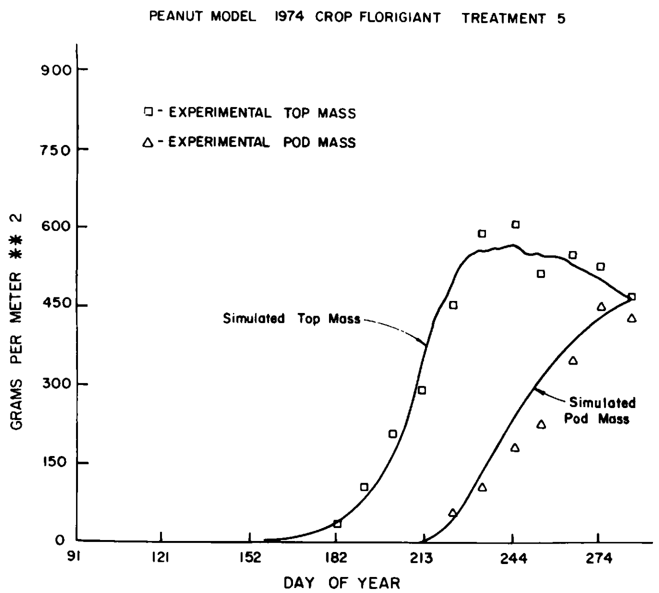

Fig. 3. Simulated and experimental top and pod growth curves for Florigiant peanuts planted on day 151 of 1974.

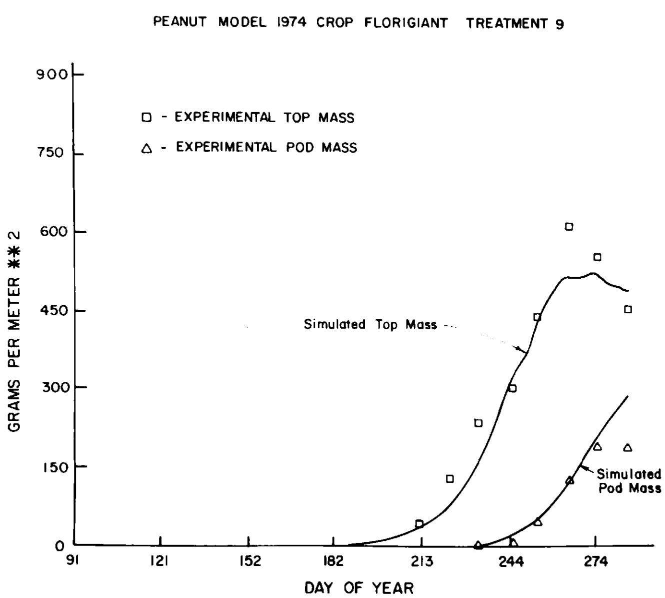

Fig. 4. Simulated and experimental top and pod growth curves for Florigiant peanuts planted on day 182 of 1974.

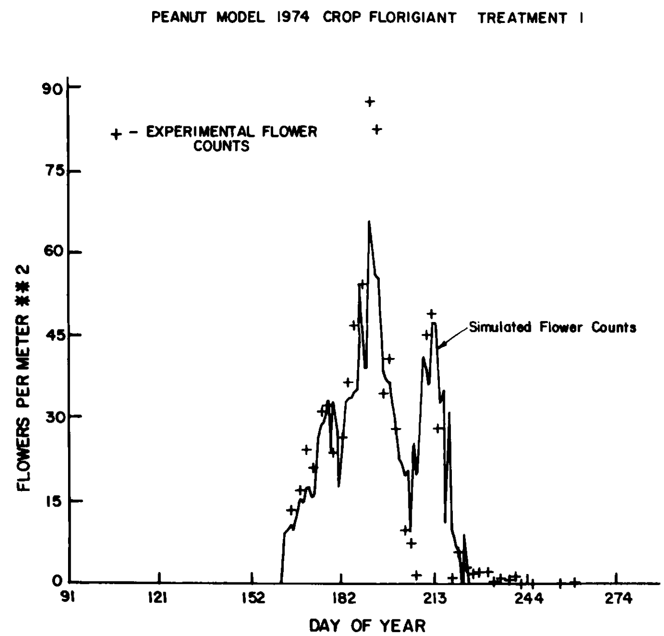

Fig. 5. Simulated and experimental flower counts for Florigiant peanuts planted on day 107 of 1974.

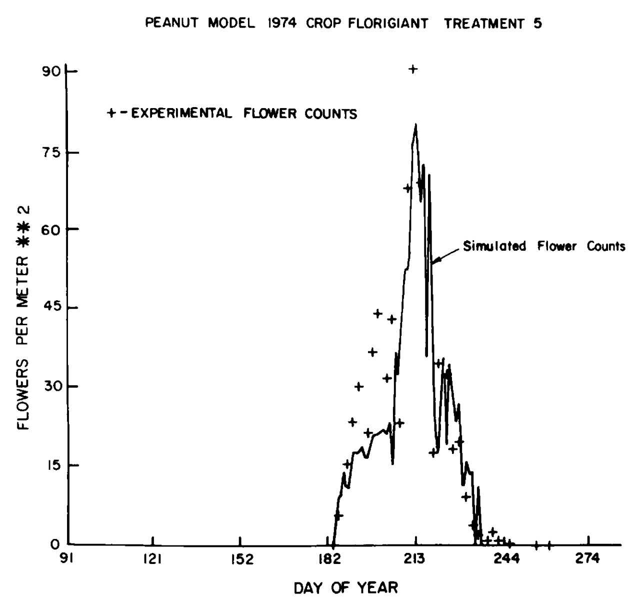

Fig. 6. Simulated and experimental flower counts for Florigiant peanuts planted on day 151 of 1974.

trolled temperature conditions have been initiated. It may be noted from Figure 8 that with the range of temperature values actually encountered during the two growing seasons the temperature factor curve does not vary greatly due to the different values of p(4) and that the relative photosynthate production rates are realistic. The temperature factor curve is unrealistic at very low and very high temperatures indicating the need for tests under a wider range of temperatures. For this reason the curve is shown as a dashed line in Figure 8 outside the temperature range actually encountered in this study.

Figure 9 indicates that most of the response to radiation occurs at total radiation levels below 8 MJ/m^2. This low level of saturation was unexpected but preliminary results from phytotron studies tend to substantiate these results. Although optimum values of p(5) in Table 1 varied widely, the resulting curves for the radiation factor were not greatly different in the range of radiation levels encountered.

Figure 10 indicates that soil moisture tension has little effect on photosynthesis rate until tensions are reached which are higher than would normally be expected. Further investigation of the soil moisture effect is underway in conjunction with irrigation studies.

Figure 11 illustrates average and extreme shading factor curves obtained for the 1974 and 1975 crops.

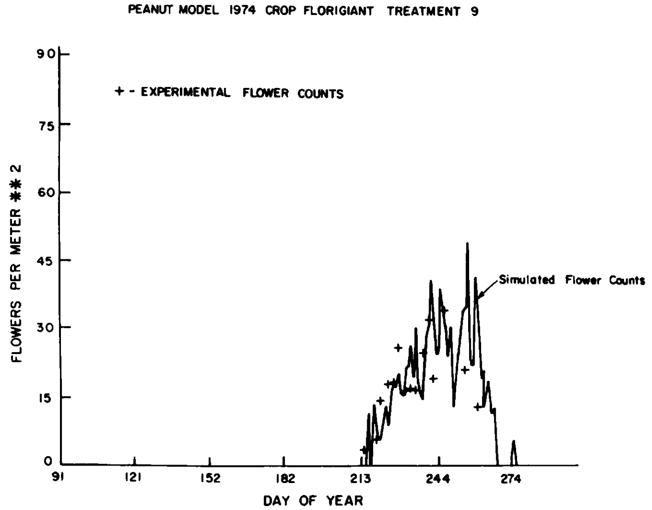

Fig. 7. Simulated and experimental flower counts for Florigiant peanuts planted on day 182 of 1974.

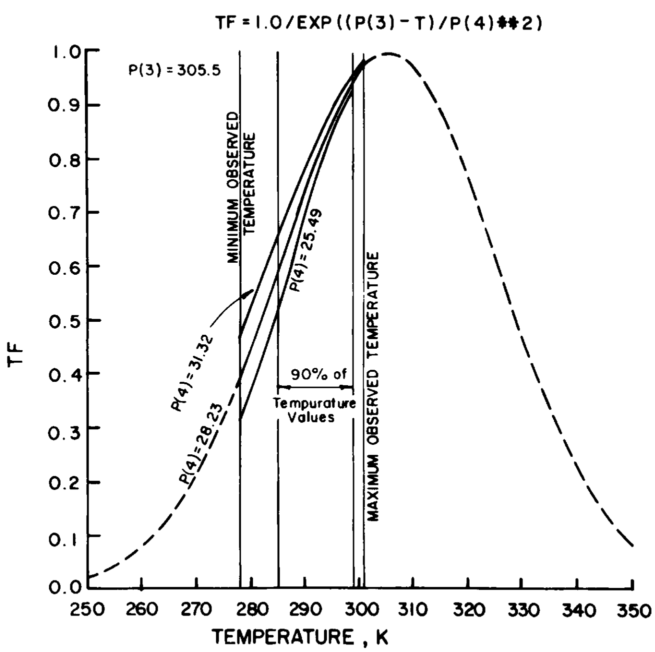

Fig. 8. Plot of temperature factor; TF, for effect of temperature on photosynthate production per unit leaf mass.

The shading factor was assumed in this initial model to be a function only of leaf mass per unit area. However, an additional radiation effect may need to be included in the model to properly simulate canopy effects since light saturation curves are different for individual leaves than for canopies (Brun and Cooper, 1967). This would allow the radiation factor of Figure 9 to represent the radiation effect on individual leaves while the shading factor would adjust for the effect that varying radiation levels have on overall efficiency of light utilization in the canopy.

Table 1 indicates significant variation between years and varieties for some parameter values. This implies additional environmental effects need to be included. However, some of the more important parameters related to photosynthate production (Example: p(10)) remain constant and as shown in the case of p(5) the wide variation of many other parameters had much smaller effects on the quantitites calculated from them. In order to get better values of the parameters it is necessary that experiments under controlled conditions be performed rather than fitting growth curves in which varying weather conditions are encountered throughout the season.

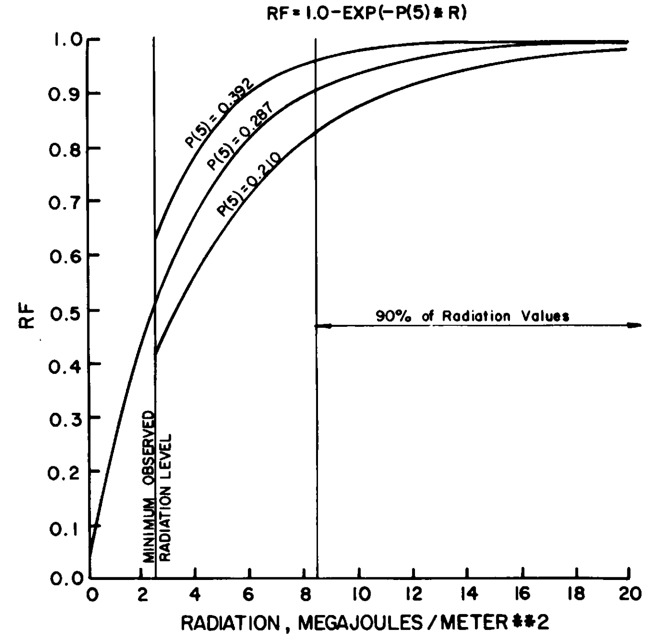

Fig. 9. Plot of radiation factor, RF, for effect of radiation on photosynthate production per unit leaf mass.

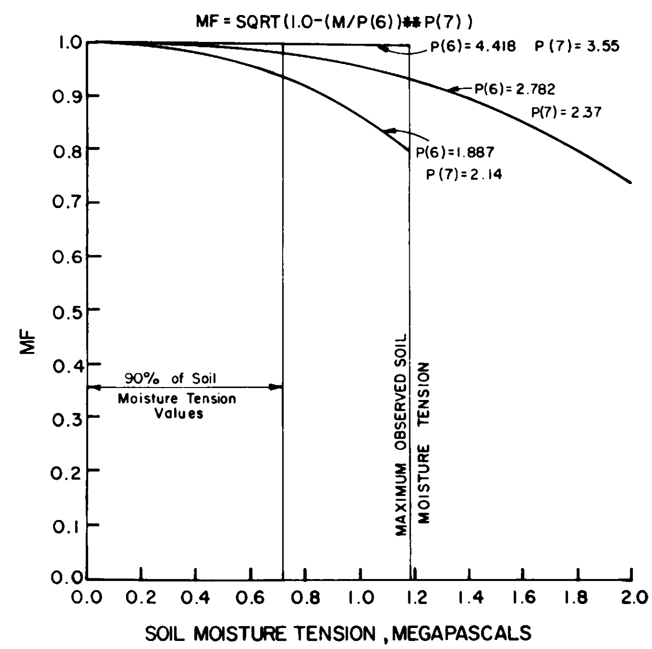

Fig. 10. Plot of soil moisture factor, MF, for effect of soil moisture on photosynthate production per unit leaf mass.

Summary and Conclusions

A computer model has been developed to simulate

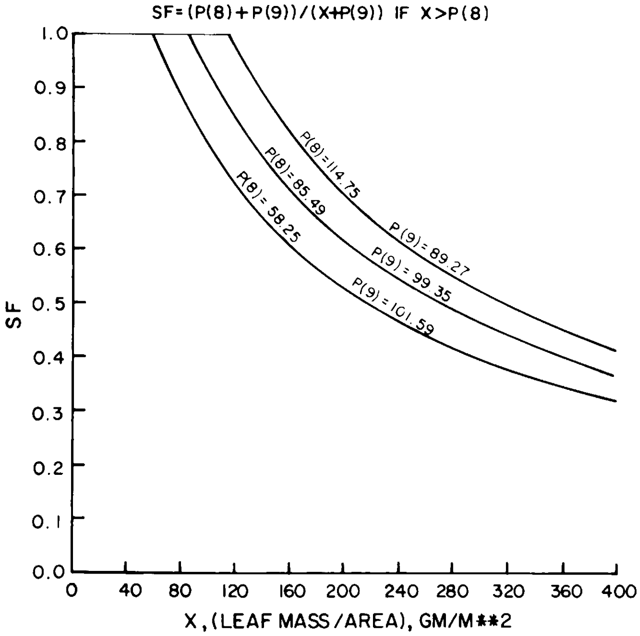

Fig. 11. Plot of shading factor, SF, for effect of vegetative growth on photosynthate production per unit leaf mass.

the growth of peanuts. The model is based on a number of assumptions which need further investigation but initial indications are that the model can be used to give reasonable approximations of actual growth. Efforts toward development of the peanut growth model have identified a number of areas in which basic information is either sketchy or totally lacking. These include the manner in which photosynthate production is affected by various environmental parameters and the manner in which photosynthate is distributed among the various plant components. Also, very little published information exists for peanuts concerning the mechanism for triggering the development of a flower and then determining whether a peg and subsequently a pod will be formed. The effects of stress conditions (due to moisture, temperature, etc.) on plant development are also largely unknown. For example, if photosynthate production cannot meet the pod development demand, we do not have sufficient information to say whether all developing pods suffer, whether the oldest pods have priority for photosynthate thus causing the "death" of younger pods, or there is some other reaction to the stress conditions. Thus there is a great need for quantitative information concerning basic physiological development of the peanut plant.

An area of the growth simulation which has not been addressed in studies to date is the influence of disease, insects, and competing vegetation on the development of the peanut plant. Plans for the future include the initiation of prototype models for peanut pests. The present growth simulation model has also neglected the development of the peanut root system. This is equivalent to assuming that a fixed fraction of the photosynthate produced goes into root growth. This phase of peanut growth needs further attention since variations in root development may effect the response of the plant to moisture stress.

Literature Cited

1. Bowen, H. D., R. F. Colwick, and D. G. Batchlder, 1973. Computer simulation of crop production - potential and hazards. Agricultural Engineering 54:42-45.

2. Brun, W. A. and R. L. Cooper, 1967. Effects of light intensity and carbon dioxide concentration on photosynthetic rate of soybean. Crop Sci. 7:451-454.

3. Cox, F. R. and C. K. Martin, 1974. Effect of temperature on time from planting to flowering in Virginia-type peanuts (Arachis hypogaea L.). Peanut Sci, 1:86-90.

4. Chhinnan, M. S. and J. H. Young, 1976. A study of diffusion equations describing moisture movement in peanut pods. I. Comparison of vapor and liquid diffusion equations. Transactions of ASAE 20(3):539-546.

5. Chhinnan, M. S. and J. H. Young, 1976. A study of simultaneous vapor and liquid diffusion of moisture in peanut pods. Paper No. 76-3013 presented at 1976 Annual Meeting of Am. Soc. of Agr. Engrs. in Lincoln, Nebraska.

6. deWit, C. T., R. Browner, and F. W. T. Penning deVries, 1970. The simulation of photosynthetic systems. p. 47-70. In "Prediction and measurement of photosynthetic productivity" (IBP/PP Technical Meeting Proc., Trebon), Center for Agricultural Publishing and Documentation (PUDOC), Wageningen.

7. Duncan, W. G., 1974. PENUTZ, A simulation model for predicting growth, development, and yield of a peanut plant. Am. Peanut Res. & Educ. Assoc. Proc. 6:72. Abstract.

8. Duncan, W. G., 1975. Theoretical limits to peanut yields. Proc. of Am. Peanut Research and Educ. Assoc. 7:68. Abstract.

9. Emery, D. A., J. C. Wynne, and R. O. Hexem, 1969. A heat unit index for Virginia type peanut. I. Germination to flowering. Oleagineux 24:405-409.

10. Gallaher, R. N., R. H. Brown, D. A. Ashley, and J. B. Jones, Jr., 1976. Photosynthesis of, and $^{14}CO_2$ Photosynthate translocation from, calcium deficient leaves of crops. Crop Sci. 16: 116-119.

11. Henning, R. J., R. H. Brown, and D. A. Ashley, 1975. The effect of leaf position and plant age on photosynthesis and photosynthate translocation of peanut (Arachis Hypogaea L.). Am. Peanut Res. Educ. Assoc. Proc. 7:71. Abstract.

12. Jensen, M. E., D. C. N. Robb, and C. E. Franzoy, 1970. Scheduling irrigations using climate crop soil data. Am. Soc. Civil Eng. J., Irrig. Drain. Div. 96:25-38.

13. Mills, W. T., 1964. Heat unit system for predicting optimum harvesting time. Transactions of ASAE. 7:307-309.

14. Meyer, B. S., D. B. Anderson, and R. H. Bohning, 1960. Introduction to Plant Physiology. D. Van Nostrand Company, Inc. Princeton, New Jersey.

15. Nicholaides, J. J., F. R. Cox, and D. A. Emery, 1969. Relation between environmental factors and flowering periodicity of Virginia type peanuts. Oleagineux 24:681-683.

16. Rickman, R. W., R. E. Ramig, and R. R. Allmaras, 1975. Modeling dry matter accumulation in dryland winter wheat. Agron. Jour. 67:283-289.

17. Schenk, R. U., 1961. Development of the peanut fruit. Georgia Agric. Expt. Sta. Tech. Bull. N. S. 22.

18. Shear, G. M. and L. I. Miller, 1959. Influence of time of planting and digging on the Jumbo Runner peanut. Agron. Jour. 51:30-32.

19. Waggoner, P. E., 1969. Predicting the effect upon net photosynthesis of changes in leaf metabolism and physics. Crop Sci. 9:315-321.

20. Whitaker, T. B. and J. H. Young, 1972. Application of the vapor-diffusion equation for concentric spheres in describing moisture movement in peanut pods. Trans. of ASAE. 15: 167-171, 194.

Accepted November 25, 1978