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INTERCROPPED TOMATO AND SNAP BEAN:
A COMPUTER MODEL

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John F. Kelly
Major professor

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INTERCROPPED TOMATO AND SNAP BEAN:

A COMPUTER MODEL

By

Ian Bruce McLean

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ABSTRACT

INTERCROPPED TOMATO AND SNAP BEAN:
A COMPUTER MODEL

By

Ian Bruce McLean

A dynamic simulation model of intercropped tomato (Lycopersicon esculentum cv. PikRed) and snap bean (Phaseolus vulgaris cv. Bush Blue Lake) is presented. Beans are planted in a matrix of hexagonal rows with a tomato transplanted centrally in each hexagon. Model inputs are real weather data and shadow lengths. Carbon fixation and respiration rates for each species are computed, and photosynthate is partitioned to plant components. Canopy growth and above-ground inter- and intra-specific competition is modeled. Tomato-tomato distance is varied from 0.8 to 1.2 m, and bean-bean distance from 0.05 to 0.15 m. Bean planting date is also varied. By repeated simulations the model predicts the combinations of these three variables which optimize individual and combined species yields. Field validation experiments confirmed the predicted optimum combinations of 0.8 m tomato-tomato and 0.05 m bean-bean distances with the earliest bean planting for maximum total yield.

ACKNOWLEDGMENTS

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Financial support from Title XII funds and the People of the State of Michigan has enabled me to attend Michigan State University. I am deeply appreciative of this honor, and will strive to return some of this goodness to the communities in which I will live.

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INTRODUCTION

Multiple cropping is practiced by millions of smallholders[1] throughout tropical and subtropical Africa, Asia and Latin America. These farmers have been largely neglected by agricultural researchers aiming at increased food production. Concern has been primarily with the minority capable of incorporating segments of Western technology and achieving rapid gains dependent upon large inputs (49, 60).

Growing recognition of the widespread practice of multiple cropping throughout the tropics has led to increased research into its principles (124, 125). This dissertation is an extension of that process.

Intercropping research has focused on two main areas: first, the relative yields and competitive strengths of component species grown as intercrops and as monocultures, and second, the environmental changes occurring within the intercropped planting (46).

Classical plant competition research methods do not readily lend themselves to investigation of individual inputs into an ecosystem. A simulation model may be especially useful in testing effects of variables such as solar radiation and light utilization efficiency. Numerous simulations may be quickly and economically made while holding all but one variable constant.

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[1]More than 90% of all tropical farms are of less than 5 ha in area (49). Diverse traditional farming systems exist on these farms. Smallholder refers to a member of this large group of traditional farmers on small land holdings.

A simulation model of intercropped tomato (Lycopersicon esculentum) and snap bean (Phaseolus vulgaris) is the basis for this investigation into the effects of environmental inputs and plant spacings. This is a unique approach to the study of intercropping. Plant models for crops in monoculture have been published (9,30, 41, 53 93), but there is no published model of systematically intercropped agronomic or horticultural crops. It is intended that this model of two intercropped vegetables will provide new insight into this complex ecosystem.

The initial conceptualization of the model was performed in 1979 by a student group working on a class project for Systems Science 843 at Michigan State University (26). The model was proposed by this author. Crop growth simulation by this model failed after several days and no results were obtained. The model which forms the basis of this dissertation is conceptually derived from this first attempt by the group. The valuable assistance rendered by that initial modeling effort is gratefully acknowledged.

GENERAL LITERATURE REVIEW

A. MULTIPLE CROPPING

1. Definitions

Multiple cropping refers to the growing of mixed crops simultaneously, sole crops in sequence, or mixed and sole crops sequentially, on a unit land area per farming year[2] (6).

Two major groupings of multiple cropping patterns exist (6):

a. Sequential cropping. Two or more sole crops grow sequentially on the same field per year. No intercrop competition occurs, and the farmer manages one crop at a time on that field. Double, triple, quadruple and ratoon cropping are practiced.

b. Intercropping. Two or more crops grow simultaneously on the same field during all or part of their growth period. Intercrop competition occurs during all or part of crop growth, and the farmer manages more than one crop at a time in that field. Mixed, row, strip and relay intercropping is practiced.

2. Distribution and Characteristics

Multiple cropping is an important part of traditional farming systems throughout tropical and sub-tropical Africa, Asia and Latin

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[2] The farming year is 12 months unless aridity restricts cropping to 24 month cycles.

America. Millions of smallholders use complex cropping patterns developed through empirical experimentation (49, 60).

The high cropping intensity achieved by multiple cropping is dependent upon, or associated with, several factors (11, 49, 60).

a. Adequate water from precipitation and/or irrigation.
b. A long growing season.
c. Suitable soil conditions.
d. Small farm size.
e. High marketing costs.
f. Spreading of peak labor demands.
g. Low level of mechanization and high labor inputs.

Several benefits are derived from multiple cropping. Most important is the potential for greater total crop yield due to optimum utilization of growth resources (11, 124). Instances of substantially higher yields from sequential and intercrop patterns have been reported (7, 23, 88, 91, 126).

Associated with the possible yield advantage is "harvest insurance." If one crop fails due to climatic or other causes, the remaining crop(s) may partially compensate by producing at least some yield. Harwood et al., (49) suggest that the failing crop will already have impaired the yield of any intercrop, and that harvest insurance is an an argument for crop diversification rather than multiple cropping. Nevertheless, it is commonly mentioned in the literature as a benefit (6).

Multiple cropping may allow more effective use of family labor. Peak labor demands may be smoothed out and higher labor productivity obtained (60). Family labor may be a readily available input which multiple cropping most effectively utilizes.

Pest control in multiple cropping is especially complex. Weeds may be inhibited by the more competitive community and dense canopy of intercropped species (39, 124). However, insect and disease control is not necessarily enhanced. Instances of better control have been reported (22, 74). But poorer control has also occurred, especially in uninterrupted sequential cropping of rice (74). Integrated pest management in multiple cropping requires a planned diversity of control methods. Crop rotation, crop diversity, resistant genotypes, modified plant spatial arrangements, and judicious pesticide use where economically feasible are some control components (74, 99).

3. Multiple Cropping Examples

Multiple cropping patterns frequently involve a main crop intercropped with, or followed sequentially by, a legume or vegetable. Examples of the former are maize (Zea mays), sorghum (Sorghum spp.) or millet (Panicum miliaceum) intercropped with bean (Phaseolus vulgaris), ground nut (Arachis hypogaea), pigeon pea (Cajanus cajan), cowpea (Vigna unguiculata) or soybean (Glycine max) (2,4,10,23,84,90,100).

Examples of sequential cropping involving a cereal are rice (Oryza sativa) followed by rice and/or sweet potato (Ipomea batata), potato (Solanum tuberosum), maize (Zea mays), tobacco (Nicotiana tabacum), soybean (Glycine max), or vegetables (cucurbits, solonaceous species, cole crops, legumes, etc.) (7).

Wide diversity occurs in the number and types of crops which are combined, including numerous combinations not mentioned above. For example, variation in cultivar characteristics such as plant height and days to maturity may be exploited. Many patterns may even occur within a village. For example, about 60 different combinations were identified in a single village in India (60). Multiple cropping systems are as diverse as the cultures and geographic areas from which they have arisen.

4. Experimental Designs and Statistical Analysis

Compact experimental designs are required for intercropped plant population studies. The large number of crop spacing combinations quickly make experiments large. Several compact designs are used.

a. Fan designs in which the plant position grid is formed by the intersection of concentric circles and the equally spaced radii of the circles. Various forms emphasize changing shape or area occupied at each grid point. Methods for statistical analysis of the results are available (14,87). Willey (125) noted that fan harvest areas are particularly small, and that results from the fan may not be typical of comparable situations in conventional row designs. Therefore, he suggested a modified fan to allow row planting. Huxley, *et al.*, (58) suggested methods for interpreting the yield/population curves derived from fan designs.

b. A 2-way grid, non-systematic design which introduces randomization and permits conventional analysis of variance techniques (73).

5. Interpretation of Yield Data

The analysis of intercropping experiments has been addressed by several authors (85,86,94,125,127). These analyses generally attempt separation of the competitive abilities of the intercropped species.

The overall performance of intercropping patterns commonly has been expressed as Land Equivalent Ratio (LER). LER is defined as "the relative land area under sole crops that is required to produce the yields achieved in intercropping", given the same level of management in both situations (124). For example, an LER = 1.10 indicates that 10% more land under sole crops would be required to produce the intercropped yield.

6. Recent Research Trends

Monoculture associated with advanced mechanization has predominated in 20th century Western agriculture. This has led to the early rejection of multiple cropping by Western-trained agriculturists as primitive and inefficient. It was assumed that as modern, Western agricultural practices were explained to traditional farmers, there would be a natural adoption of these practices and multiple cropping would decline (124). This assumption has succumbed to the continued, widespread practice of multiple cropping in spite of efforts to promote monoculture among subsistence farmers (89).

Increasing recognition of multiple cropping has been reported in several reviews and books during the last decade (7,24,48,60,71,68,69, 70,92,106,124,125). These include descriptions of multiple cropping methodology in various cultures and geographic areas.

Recent research by agronomists has focused on population levels, genotype selection, pest management, nutrient and water uptake, and light interception as they influence yield (3,5,39,75,91,99,110,122,126).

7. Farming Systems Research

Cropping systems are enmeshed in the societies of which they form a part. Recent emphasis on this fact has led to the development of farming systems research (FSR). FSR seeks to "increase the productivity of the farming system in the context of the entire range of private and societal goals, given the constraints and potentials of the existing farming system" (38). Interdisciplinary FSR is currently a major component of programs at the International Rice Research Institute and the International Crops Research Institute for the Semi-Arid Tropics (66,134). FSR methodology is especially suited to the study of multiple cropping and other traditional farming methods (89,135). Its further incorporation into smallholder research will reduce the incidence of proposed technological packages which are unsuited to the socio-economic milieu of the traditional farm and village (34,89).

B. PLANT COMPETITION

Plant competition is a vital component of agronomy, ecology, horticulture and weed science. It is central to research into intercropping principles.

The classical plant competition definition is that of F. E. Clements in 1929, as cited by Hall (43).

> Competition is purely a physical process. With few exceptions, such as the crowding of tuberous plants when grown too closely, an actual struggle between competing plants never occurs. Competition arises from the reaction of one plant upon the physical factors about it and the effect of the modified factors upon its competitors. In the exact sense, two plants do not compete with each other as long as the water content, the nutrient material, the light and the heat are in excess of the needs of both. When the immediate supply of a single necessary factor falls below the combined demands of the plants competition begins.

Interference by one plant upon another may include allelopathy. Rice (102) defined allelopathy as

> ...any direct or indirect harmful effect by one plant (including microorganisms) on another through the production of chemical compounds that escape into the environment.

Interference is the sum of competition and allelopathy.

Attention was focused on plant competition research methodology in the 1950s through early 1970s. Several publications reviewed competition principles, research practices and mathematical models (13,28 29,46,47,82,107,128,129). Trenbath (118,119) reviewed plant interactions in mixed communities. A series of papers by Kira and associates dealt with intraspecific competition and density-yield relationships of several crops (54,55,62,63,64,65,133).

1. Plant Competition Research Methodology

Mathematical models of varying complexity are used to quantify plant competition.

a. Yield. Total yield as the plant population is varied is used widely in agriculture to establish optimal planting rates. Associated with this is the quantitative analysis of plant growth and yield components (46,104).

b. Environmental change from increased plant density. Light, water and nutrient level changes due to increased plant density have been studied extensively in agriculture (46). These factors are critical for crop growth and most commonly are affected by population increases.

c. Plant weight. Three measures of plant weight are used (79). First, the coefficient of variation of plant weight may increase with time at high densities. Second, the frequency distribution of individual weights in a plant population may change from "bell-shaped" to "L-shaped" during growth. Third, the correlation between a plant's weight and the weights of neighboring plants may indicate cooperative or competitive situations.

d. Mixture diallel. The diallel design is used by geneticists and agronomists to compare the relative performance of a number of species or genotypes (86). Adaptations of this design to competition studies are available (45,86,101, 127).

e. Replacement series and derived functions. The replacement series technique originated by de Wit (128) and expanded by de Wit *et al*., and Hall (43), (132) is widely used in plant competition research (124). Two or more species are grown together in different proportions and in monoculture. The two species' yields are represented on two Y axes, and their relative population proportions on the intersecting X axis. Lines join yield levels at component portions from 0 to 100% of the total population. Interpretation of the resultant diagram places the interspecific relationship in one of three broad categories: mutual cooperation, mutual inhibition, or compensation.

Functions developed by de Wit and associates assist in competition analysis (128). The relative reproductive rate of two or more annuals is the ratio of number of seeds sown to number of seeds harvested. The relative replacement rate is derived by resowing seeds of both species previously harvested from monocultures and mixtures and is closely related to the relative reproductive rate. The relative crowding coefficient measures the activity of a species when crowding another species for space.

f. <u>Lotka-Volterra equations and Land Equivalent Ratio</u>. A theoretical explanation of LER > 1 using the classical Lotka-Volterra equations describing two interacting populations was reported (121). Vandermeer (121) showed that for LER to exceed 1 the mutual interference of the two species must be sufficiently weak. He also showed that LER is mathematically identical to the competitive exclusion principle of theoretical ecology.

2. Future Research Needs

Incorporation of the above principles into multiple cropping research must be expanded. Presently there are few instances of the use of ecological principles and research methods in the applied multiple cropping literature. Willey (124,125) clearly outlined their potential applications. A fertile research area awaits workers capable of bridging the two fields.

C. THE SYSTEMS APPROACH AND MODELING

The reductionist approach to scientific research reduces phenomena to their basic parts. Independence of the parts is requisite. Reductionism leads to the fragmentation and proliferation of disciplines which remain essentially isolated.

The expansionist approach assumes that all entities and phenomena are parts of greater wholes. Interdependence of objects and events is declared. Holistic, interdisciplinary team research is integral to expansionism (27). The systems approach is formalized expansionism.

1. Definitions

De Michelle (81) defined a system as

> ...an assemblage of objects united by some form of regular interaction or interdependence. It is an identifiable portion of the real world about which we can construct a boundary. Through this boundary we monitor or control all inputs and outputs.

An ecosystem has living organisms as some of its objects (113). An agro-ecosystem adds stricter control over the ecosystem boundary and its inputs and outputs (78).

A model of some sort is essential to systems study. The model is a "set of hypotheses about the system cast in the form of a set of mathematical equations" (81). Systems simulation is problem solving using a dynamic model over time (8).

Two types of models are identified (81).

a. <u>Descriptive</u> (<u>from observed responses</u>). Responses are recalled from similar past circumstances. Curves are fitted to experimental data and used predictively. Nothing new is learned about the system.

b. <u>Mechanistic</u> (<u>from fundamental concepts</u>). A set of equations describe hypotheses about events occurring within the system. New insights into system behavior are sought.

Models may initially be descriptive, and become increasingly mechanistic through refinement.

2. Reasons for Agricultural Simulation

Several benefits are derived from the modeling process itself, and from crop simulation(8,15,81,96).

a. Insight may be gained into a system whose component interactions are too numerous and complex to be comprehended otherwise.

b. Interdisciplinary coordination of research efforts may reveal and remedy information lacunae. New knowledge from this research may be stored and used in the model.

c. New hypotheses may be generated and tested.

d. New knowledge may be gained from the model since the system is more than its isolated parts.

e. Agricultural management systems may be optimized.

f. Agricultural problems may be examined which otherwise are intractable due to time, cost or disruption constraints.

3. Crop Modeling Applications

a. Historical view. Pioneering work in crop modeling in the 1960s was by de Wit at Wageningen, Duncan at the Universities of Kentucky and Florida, and Stapleton at the University of Arizona (81,114) During the last decade plant modeling groups have been active at the Agricultural University at Wageningen (Netherlands), the Glasshouse Crops Research Institute (Littlehampton, England), Mississippi State University, Ohio Agricultural Research and Development Center, Purdue University and University of California (Berkeley). Several books and reviews specifically addressed to crop modeling have been published (8,25,31,77,116,131). Two journals, Agricultural Systems and Agro-Ecosystems, are devoted exclusively to extensive agricultural systems and modeling articles. A number of other journals publish plant models.

b. Examples of plant models. A model-building prerequisite is the establishment of its operational level. The model's goals largely establish its resolution. Plant models exist with levels ranging from enzyme kinetics and gas diffusion, to the whole plant (9,76).

(1) Plant physiological processes.

Models exist for light interception, photosynthesis, respiration, evapotranspiration and partitioning of carbohydrate (1,21,35, 50,56,76,108,116,120,131). No attempts to simulate plant hormone control have been published.

(2) Organ level.

The growth of several plant organs has been modeled. These include leaves, roots and flowers (18,19,20,37). To date, no model has been published of fruit growth *per se*.

(3) Whole plant level.

Whole plant models for several species now exist. The first whole plant model was of cotton, and models of this species have continued to be developed (41,114) Models of other economic species include alfalfa, apple, maize, ryegrass, soybean, sugar beet, tomato, and a management model for asparagus (9,30,32,53,57,71,80,93,109,117).

Modeling has been utilized heavily in pest management research and plant models have been required for plant-herbivore models. An example is the cotton-herbivore interaction (123).

MATERIALS AND METHODS

A. SPECIES SELECTION

1. Criteria

Vegetables form an integral part of intercropping systems in the tropics (92). However, the bulk of intercropping research has been with agronomic crops. Two vegetables were selected for this study to increase knowledge about vegetable intercropping.

The first criterion for species selection was wide adaptation throughout temperate to tropical zones. Availability of a comprehensive literature was required for both species. The two canopies were to combine readily into a cropping pattern. Tomato (*Lycopersicon esculentum*) was selected to be intercropped with either pea (*Pisum sativum*), snap bean (*Phaseolus vulgaris*), or cabbage (*Brassica oleracea* var. *capitata*).

2. Preliminary Field Experiment

Preliminary experiments were carried out at the Michigan State University Horticulture Research Center in 1978 and 1979 to assist intercrop species selection. On May 2, 1978, cabbage plants (cv. Market Victor) were transplanted .46 m apart, and peas (cv. Lincoln) direct-seeded .05 m apart, in 1.5 m rows which were 7.6 m long. Bush snap beans (cv. Bush Blue Lake) were direct-seeded .05 m apart in similar rows on May 29. On the same day, low lying determinate hybrid tomato plants (cv. PikRed) were transplanted .76 m apart in rows exactly centered between the cabbage, bean and pea rows. A tomato row was also planted without any intercrop. Monocultures of each intercropped species were also grown at the end of the plot in .76 m rows at the same density within the row as above. The treatments were replicated four times. Prior to planting, 64 kg/ha of 5-20-20 fertilizer was added to the Capac loam soil, and the field was sprayed with Treflan. The tomatoes were side-dressed on July 19 with 9 kg/ha of N. The experiment was repeated on essentially the same dates in 1979.

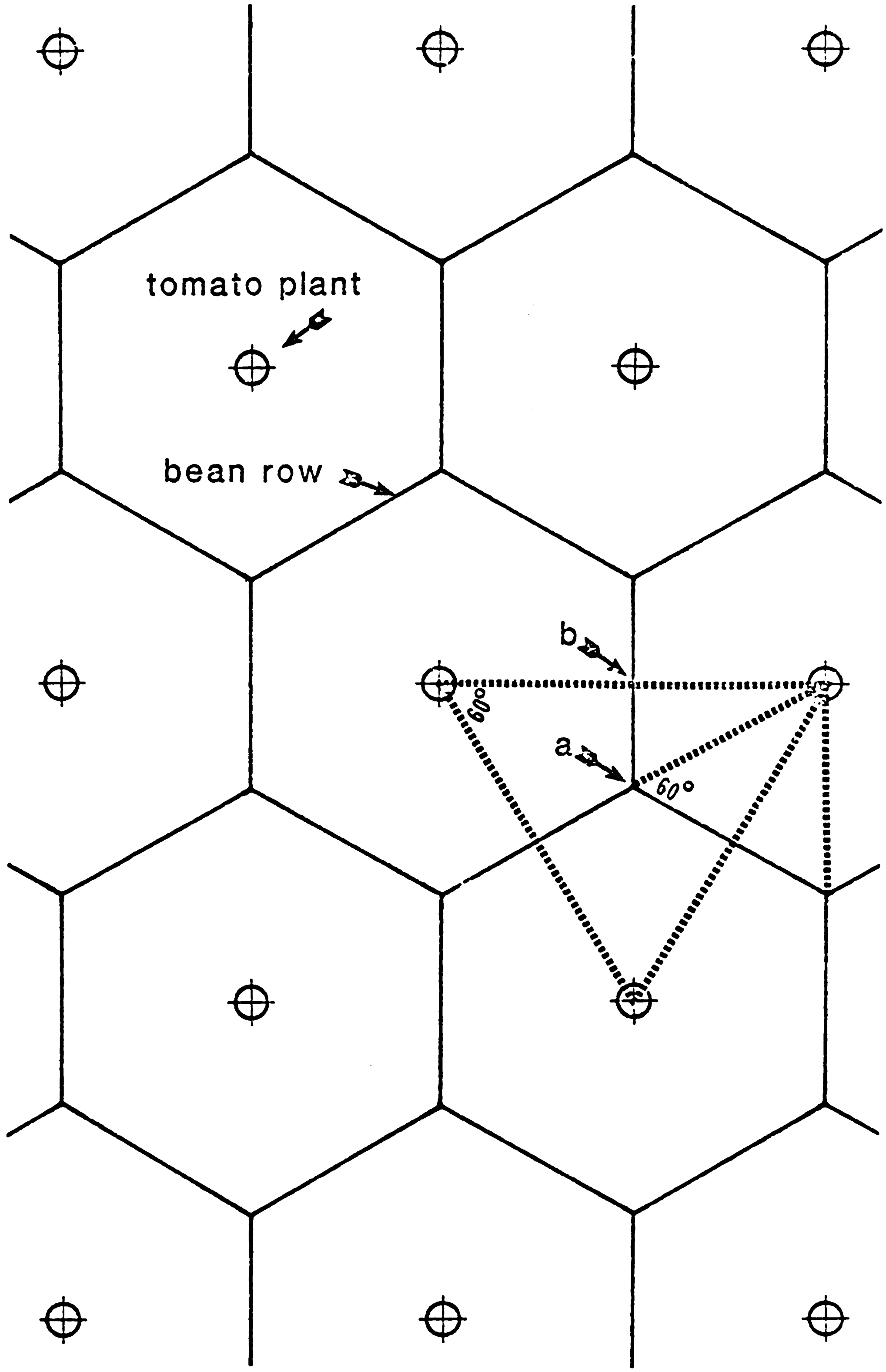
Harvest was performed by hand, and the cabbage, bean and pea plants were removed from the field after harvest. The results of this preliminary experiment are presented in Appendix A.

The three intercropped species affected the tomato yields differently, due partly to their different planting dates and growth stages at planting (transplant or seed). These differences influenced their relative competitive effect on the tomato plants. The beans had the least deleterious effect on tomato yields in 1978. The 1979 results were less conclusive due to a latent infestation of quackgrass (Agropyron repens). Due to these results and the excellent literature available for Phaseolus vulgaris, this species was selected to be intercropped with tomato. Bean cv. 'Bush Blue Lake' was especially suitable due to its short harvest period.

B. INTERCROP PLANTING DESIGN

Hexagonal bean rows with single tomato plants located centrally in the hexagon form the planting design (Figure 1). Each hexagon side with its adjacent tomato plants may be considered a segment of a straight row.

Figure 1. Hexagonal planting design with bean rows placed between equidistant tomato plants.


tomato plant
bean row
b
60°
a
60°

Hexagon symmetry allows simplification of the model. All tomato plants are equidistant and effectively separated by the dense bean canopy. They are assumed to be identical and non-competing with each other. This assumption is maintained after bean plant removal following bean harvest. The tomato plants are sufficiently separated to have little competitive effect. All tomato plants in the field are, therefore, represented by one plant in the model.

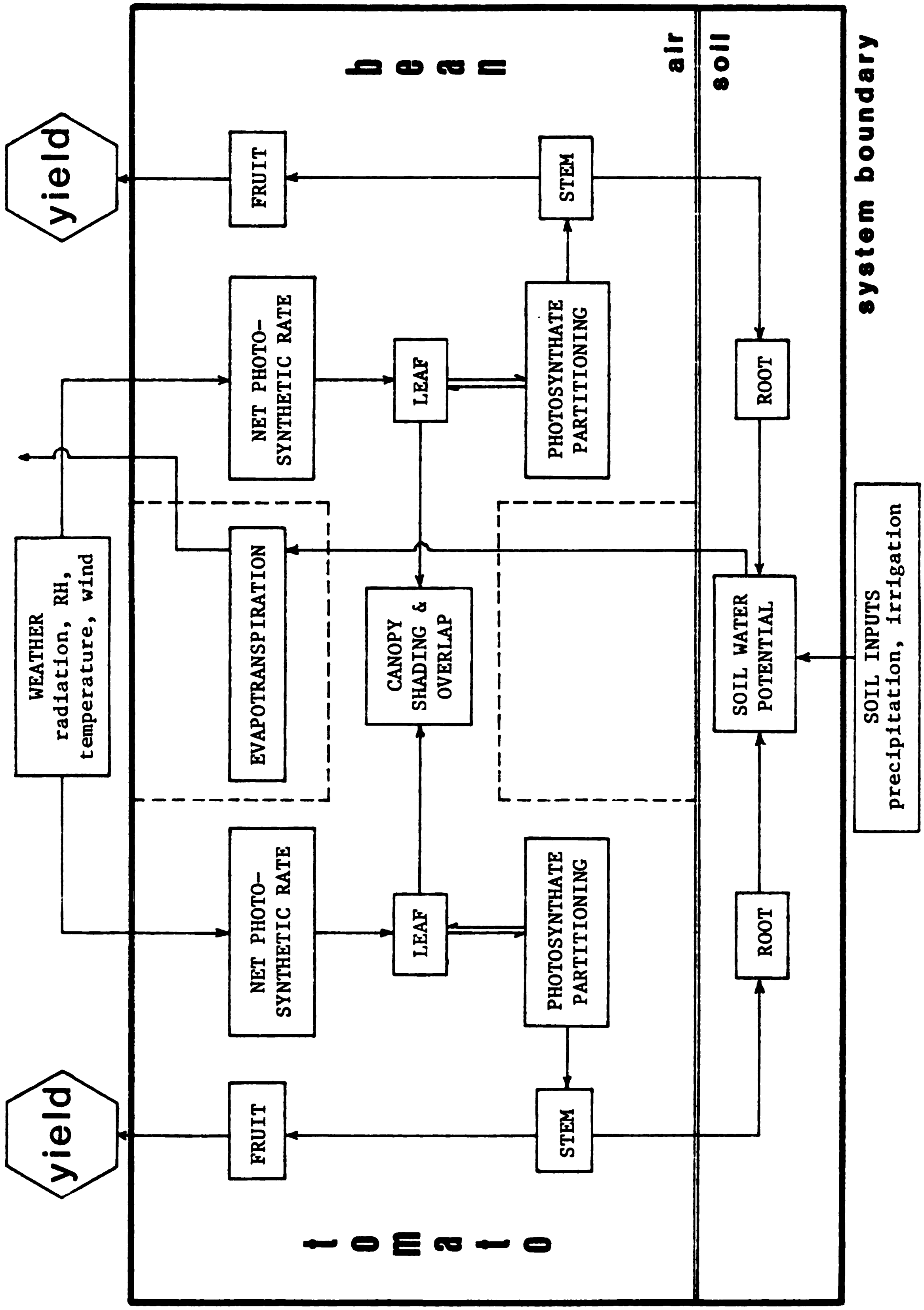
All bean plants are similarly located with respect to the tomato plants. The bean plant at position a in Figure 2 is approximately 15% further from the tomato plants than that at position b. Also, it is adjacent to three tomato plants rather than two. However, it is assumed that bean plants located at position b are representative of all bean plants in the field.

The hexagons form convenient experimental units and pack perfectly in a matrix. The tomato plant yield is entirely allocated to its enclosing hexagon. The associated bean yield is divided equally between the two hexagons whose boundary it forms.

The model allows for a range of tomato-tomato distances. This distance automatically sets the hexagon width, circumference and area. The bean-bean distance within the row may also be adjusted. These two parameters (tomato-tomato and bean-bean distances) define the component and total plant populations.

Hexagonal planting patterns were used previously in plant competition research (47,63,81). Single plants located at hexagon corners were surrounded by various mixtures of their own and other species. Hexagonal planting patterns are recommended in the biodynamic/French intensive organic farming technique (59).

Figure 2. System diagram of MULTICROP


yield
FRUIT
STEM
NET PHOTO-
SYNTHETIC RATE
LEAF
PHOTOSYNTHATE
PARTITIONING
bean
air
soil
ROOT
system boundary
WEATHER
radiation, RH,
temperature, wind
EVAPOTRANSPIRATION
CANOPY
SHADING &
OVERLAP
SOIL WATER
POTENTIAL
SOIL INPUTS
precipitation, irrigation
NET PHOTO-
SYNTHETIC RATE
LEAF
PHOTOSYNTHATE
PARTITIONING
ROOT
yield
FRUIT
STEM
tomato

C. MODEL CONDITIONS

1. System Boundary[3]

The system is located in the field with the upper boundary 2 m above the crop. The lower boundary is .3 m below the soil surface.

2. Driving Variables

The model driving variables are exogenous weather inputs. Solar radiation data in langleys was recorded hourly by a pyranometer and strip chart recorder located approximately 2 miles from the Horticulture Research Center. These data were accumulated and punched onto computer cards by the Agricultural Engineering Department. A permanent magnetic tape file of solar radiation data was created for the period May 20 to September 30 in 1968-1970, and is accessed by the model. No solar radiation data exist for Lansing for the 1980 summer due to failure of the above instrument. The simulations are, therefore, run using the above years' data. The weather of 1970 is most similar to that of 1980.

Temperature (°F), windspeed (knots) and relative humidity data were recorded at Lansing airport and obtained from the National Weather Service via the Michigan Department of Agriculture Weather Service. A program was written to read these tapes and create a permanent file accessed by the model. These data are for 3 hour blocks.

Rain (inch) data were obtained from Local Climatological Data, U.S. Department of Commerce, for Lansing, Michigan. A permanent file of these data is read by the model at 0100 hr daily and the full

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[3]For a glossary of modeling terms see Appendix B.

precipitation for that day is assumed to have been received.

Shadow lengths specific for 42° latitude, month, day and hour were obtained from the U.S. Forest Service (44) and are read into an array in the main program.

3. Initial Plant Description in the Model

At simulation commencement the tomato plants are represented as transplants planted 21 days previously with canopies .2 m in diameter. The bean plant canopies are .1 m in diameter after 7-10 days growth following seeding in the field. The tomato plant growing season commences on June 23 and terminates on September 11 after 81 days. The bean plant season is 52 days long and may commence on or after day 1 of the tomato plant season.

4. Variables for Testing

The primary aim of the model is to predict optimum planting distances and relative planting dates for the two species to ensure maximum yield. The model satisfactorily allows hexagon widths as low as .5 m and bean-bean distances of .02 m. No upper limits are defined, so isolated plants of both species may be modeled.

In the model the tomato commencement date is fixed. The bean commencement date may be retarded as late as July 22. In this way the competitive effect of the bean canopy on the tomato plant may be varied.

The model may be driven with any weather data which is in the required form. Weather data from three quite different years were selected to test the model's response to its exogenous driving variables. Summaries from National Weather Service data for these three years are presented in Appendix C.

D. MODEL DESCRIPTION

1. Overview

The model consists of state, rate and driving variables, and constants. Driving variables supply exogenous data which are used to compute rates of carbohydrate production, loss and translocation, etc. State variables are updated by the rate variables and their values are retained for the iteration. This process is repeated on a 1 hr time-step throughout the growing season, resulting in 1944 iterations per simulation. A conceptual diagram of the model, named MULTICROP, appears in Figure 2.

The model structure consists of a main program with 7 subroutines. The main program controls the simulation. Each subroutine is a submodel which performs a segment of the simulation.

The model language is FORTRAN 4 adapted for use on the Cyber 750 computer at Michigan State University. Program execution time is approximately 2.2 seconds per 81 day simulation. The program was written by the author and is intended for interactive operation. A complete listing of the program appears in Appendix D.

2. Main Program (Program DRIVER)

The main program is in 3 sections (Figure 3).

a. Information is passed between DRIVER and the subroutines in COMMON. Storage arrays for variable values to be printed following the simulation are established. Data for shadow lengths are read into an array. Initial values for bean-bean and tomato-tomato distances, bean commencement and

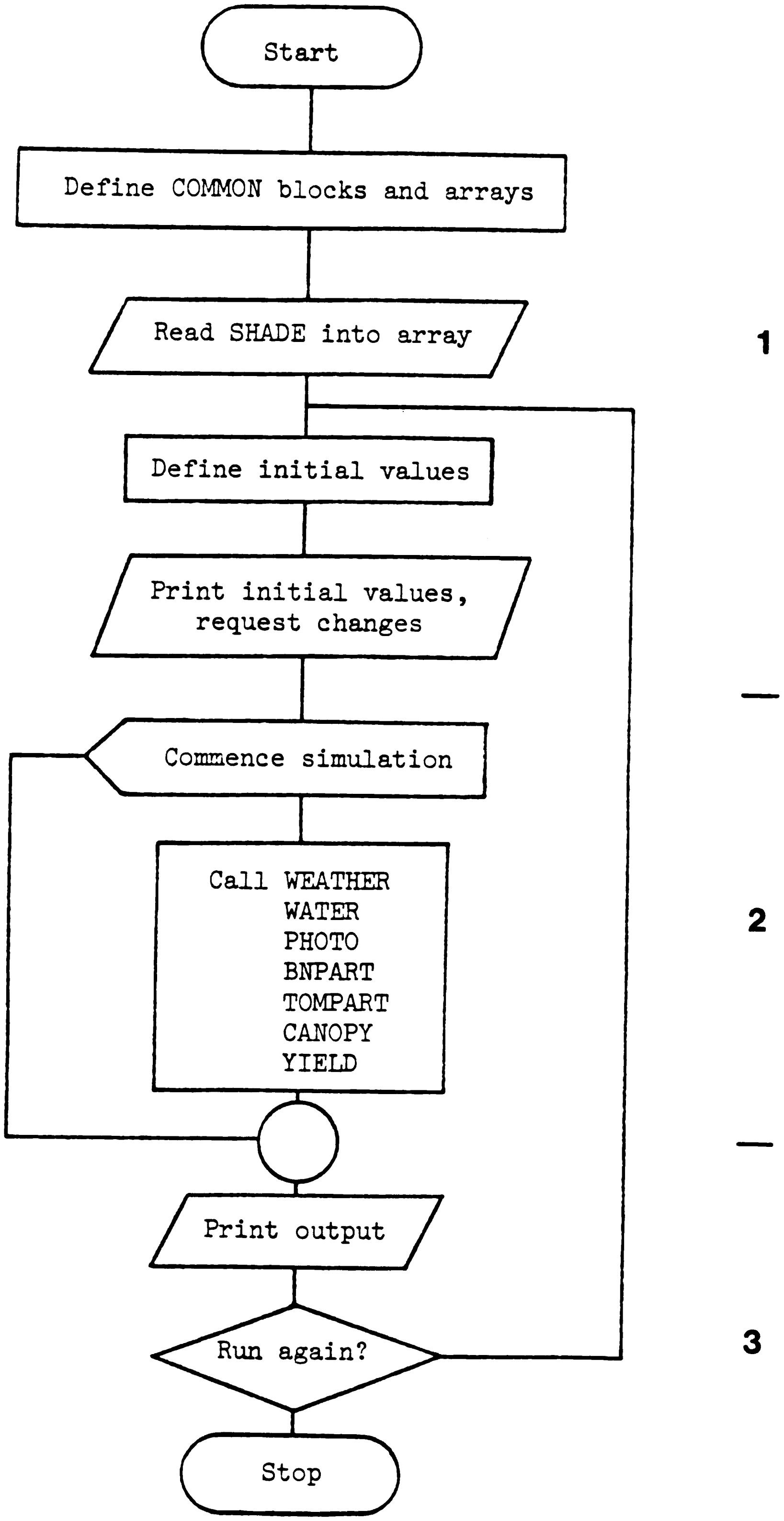


Figure 3. System diagram of PROGRAM DRIVER

harvest dates, and the print type are set. The operator is asked for any changes to these initial values.

Four print types are available. The operator may request printing of variable values stored daily at 1200 and 2400 hr, daily at 2400 hr only, final variable values only, or final yield values only.

b. The simulation is controlled by a single DO loop. Counters for day and hour are advanced and subroutines are called. The correct sequencing of operations within and between subroutines is paramount.

c. Upon completion of the simulation the program exits the DO loop and prints as previously defined. The operator is asked to specify printing at the terminal or disposal to a printer. Following printing, the program requests instruction for futher simulations, or termination.

3. Weather Data (Subroutine WEATHER)

This subroutine reads 3 weather files which are attached prior to program execution (Figure 4). Data are read daily and stored for use throughout each of the following 24 hr. No unit conversions are made. The subroutine is called only at 0100 hr.

4. Evapotranspiration and Soil Water (Subroutine WATER)

All weather inputs are adjusted to their correct units in this subroutine. Those not used here are accessed elsewhere through COMMON (Figure 5).

The evapotranspiration, soil water and leaf water potential

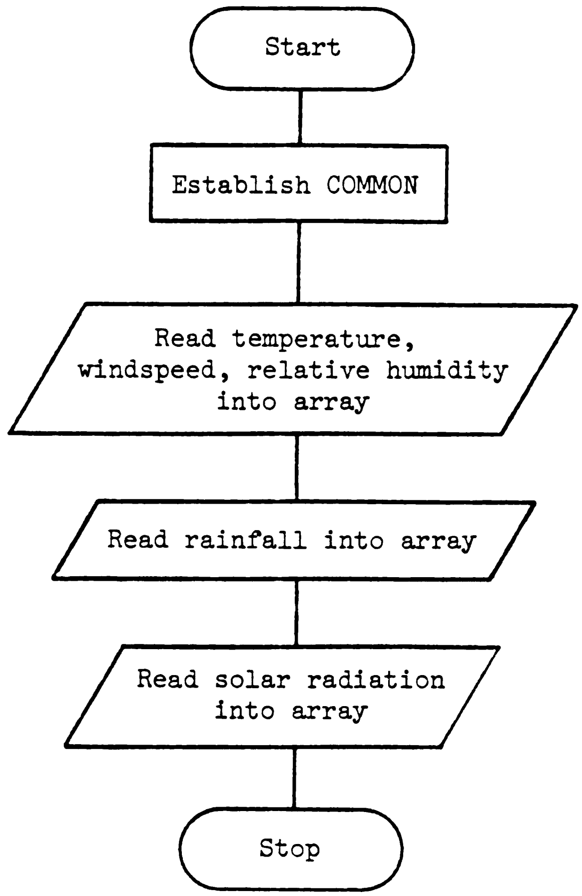
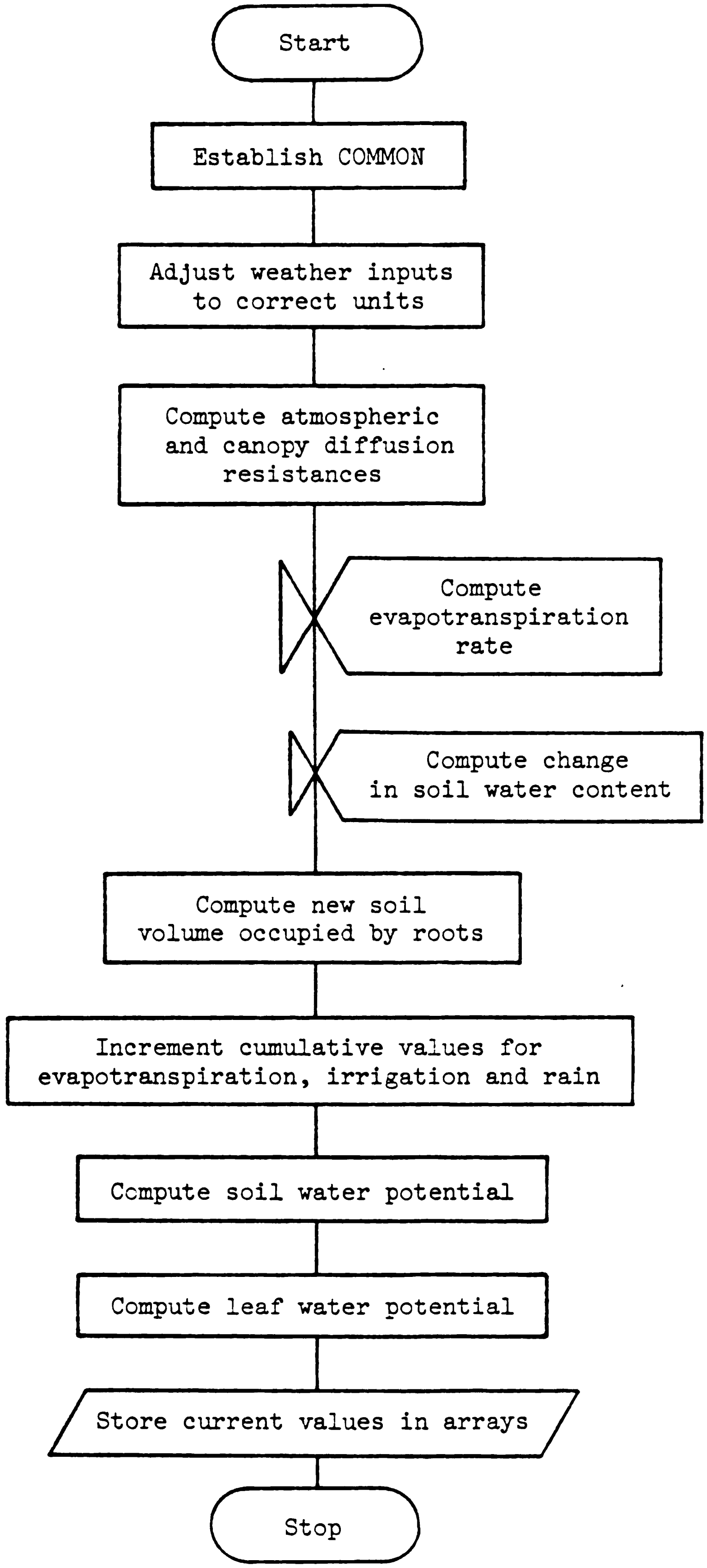


Figure 4. System diagram of Subroutine WEATHER

Figure 5. System diagram of Subroutine WATER


Start
Establish COMMON
Adjust weather inputs to correct units
Compute atmospheric and canopy diffusion resistances
Compute evapotranspiration rate
Compute change in soil water content
Compute new soil volume occupied by roots
Increment cumulative values for evapotranspiration, irrigation and rain
Compute soil water potential
Compute leaf water potential
Store current values in arrays
Stop

sections of this subroutine are adapted from subroutine WATER in SOYMOD/OARDC (82). This model is a dynamic simulation of soybean (Glycine max) growth, development and seed yield. Modifications have been made to adapt the logic to the requirements and variable of MULTICROP. However, the section remains essentially the same as subroutine WATER in SOYMOD/OARDC.

The evapotranspiration rate is computed using a modified Penman equation after Monteith (85) (Figure 6). Atmospheric diffusion resistance is assumed to be a function of wind velocity above the canopy (130).

$$\text{ATMDRES} = 8.28 / \text{WINDSPD}$$

where:

$$\text{WINDSPD} = \text{wind speed m s}^{-1}$$

The canopy diffusion resistance utilizes stomatal diffusion resistance and leaf area index (LAI). Stomatal diffusion resistance is assumed to be the same for both crops. It is computed by a function derived from bean (Phaseolus vulgaris) data (105), and is solely dependent upon temperature. Canopy diffusion resistance is then computed from stomatal diffusion resistance divided by the total leaf area per unit ground area (2 LAI) (12). The LAI used is for tomato both prior to and after bean growth. During bean growth the LAI used is for bean because of the relative spatial dominance of the bean canopy.

The evapotranspiration function assumes a closed canopy and no soil surface evaporation. This is a shortcoming of this subroutine, particularly early in the season and in the absence of the bean canopy.

$$\text{EVAPOTN} = \frac{((\text{DELTA} \times 1.5 \times \text{PAR}) + (290. \times (\text{VAPSAT} - \text{ATMDRES}) \times 10^{-6}}{(\text{DELTA} + \text{GAMMA} \times (1. + \text{CANDRES} / \text{ATMDRES})) \times 585.}$$

where:

ATMDRES = atmospheric diffusion resistance s cm^{-1}

CANDRES = canopy diffusion resistance s cm^{-1}

DELTA = (.0712 - .0004596 x TEMP) x VAPSAT

EVAPOTN = evapotranspiration rate m hr^{-1}

GAMMA = constant mbar

PAR = photosynthetically active radiation incident at the top of the canopy erg cm^{-2} s^{-1}

TEMP = temperature C

VAPSAT = saturated vapor pressure at current temperature bar

VAPTEMP = actual vapor pressure bar

Figure 6. Evapotranspiration function after Monteith (85).

Following computation of evapotranspiration, the soil water content is updated. Inputs are rain and irrigation, and the output is evapotranspiration. No irrigation is involved in the simulation but the capacity to use it is there. The model does not allow for surface runoff or losses to the water table.

The soil volume modeled is a cone directly under a bean or tomato plant selected according to the same criteria as was LAI. The cone depth is set at .3 m which was the maximum effective depth of the root systems on the Capac loam. A heavy clay layer prevented deeper root penetration (Figure 7) (112). The cone radius was assumed to be the tomato radius, or the bean radius in the direction perpendicular to the row.

Soil water potential is computed from soil water content and bulk density.

$$\text{SWPOT} = 42.61 \times e^{(-15.27 \times \text{SWC}/\text{SOILBD})}$$

where:

SOILBD = soil bulk density g cm^{-3}
SWC = volumetric soil water content
SWPOT = soil water potential bar

This function is for Wooster silt loam and is derived from data by Brady _et al_. (16). It is an approximation for the Capac loam.

Leaf water potential is computed from soil water potential.

$$\text{LFWPOTL} = 2.61 \times e^{(.161 \times \text{SWPOT})}$$

where:

LFWPOTL = leaf water potential bar

This function is for soybean (_Glycine max_) and is an approximation for the two crops modeled here.

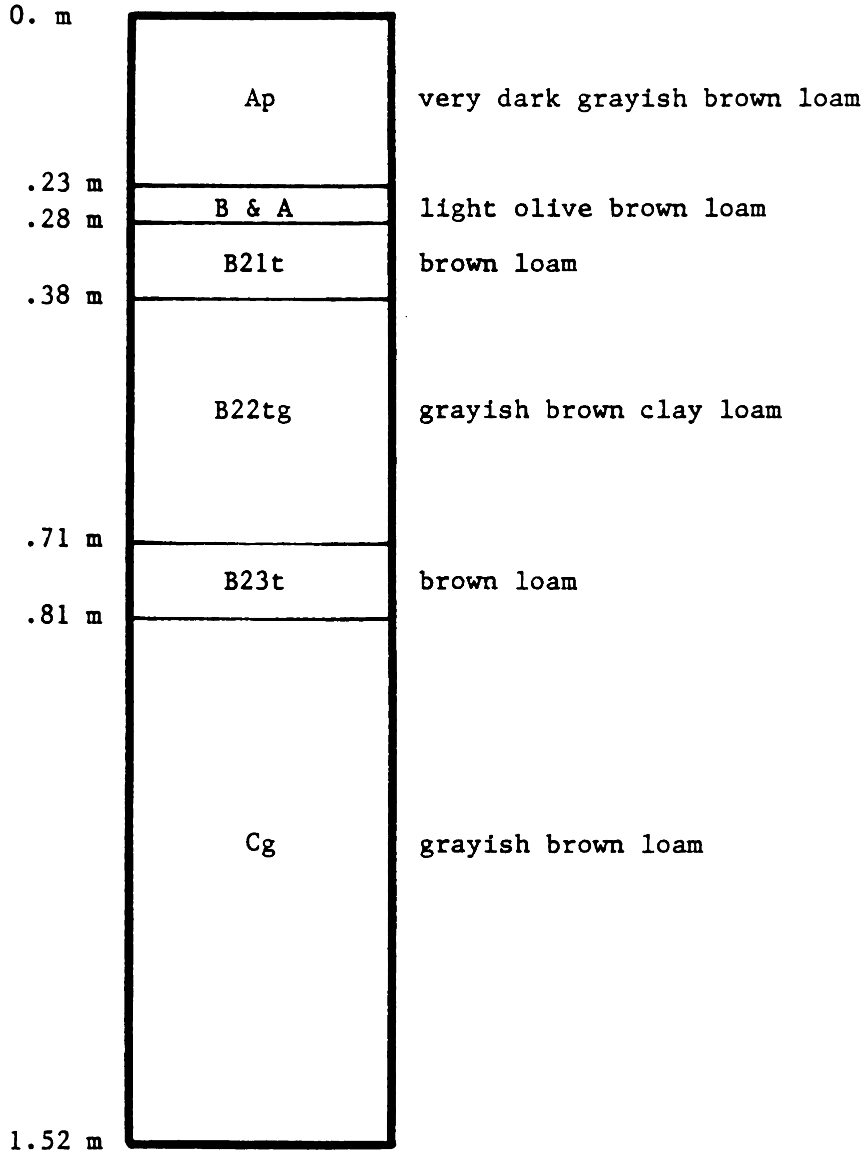


Figure 7. Soil profile of the somewhat poorly drained Capac loam.

The final step in WATER is to store variables for printing. The 1200 hr and 2400 hr values are placed into arrays through COMMON and are later printed as a block. All following subroutines act identically.

5. Photosynthesis and Respiration (Subroutine PHOTO)

This subroutine computes bean and tomato plant net photosynthetic rates in full sun and 60% shade. Photosynthate produced in grams of glucose for each species is the subroutine output (Figure 8).

Dark respiration rates for the canopies of both species are calculated according to the method of Acock *et al.*, (1) (Figure 9). The function is used identically for both species. Different respiration rates arise because of their different LAI. The equation integrates respiration over the entire leaf area of the canopy. A deficiency of this model is that the rate is unaffected by diurnal light changes. However, the average light flux density at the top of the canopy over the most recent 7 days indicates recent photosynthetic history and is used to modify respiration rate.

Stem, root and fruit respiration is assumed to be 1/3 of leaf respiration. Acock *et al.*, found this to be a fair approximation (1).

The total plant respiration is adjusted for temperature with $Q_{10} = 2$, and optimum temperature set at 25 C (53).

Photosynthetic rates for both species are calculated according to the same Acock, *et al.* model (1). The canopy photosynthetic rate function is shown in Figure 10. The function is the same for both species.

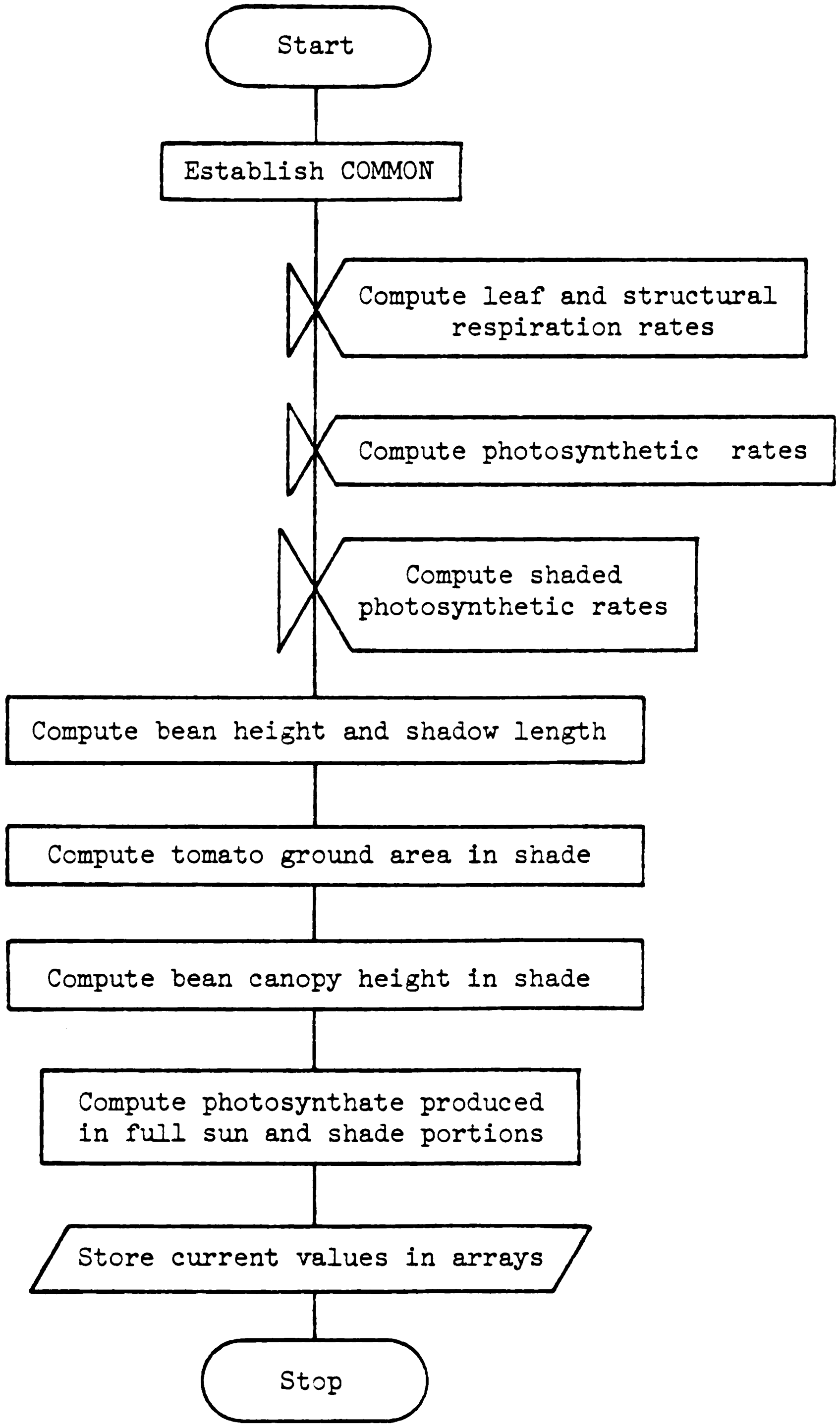


Figure 8. System diagram of Subroutine PHOTO

$$\text{TLFRESP} = \frac{\text{TX}}{\text{TX} \times \text{TEXCOEF}} \ln \left[\frac{(1 - \text{TTRANS}) + (\text{TY} \times \text{AVENRGY} \times \text{TEXCOEF})}{(1 - \text{TTRANS}) + (\text{TY} \times \text{AVENRGY} \times \text{TEXCOEF} \times \exp(-\text{TEXCOEF} \times \text{TLAI}))} \right]$$

where:

AVENRGY = average light flux density incident at the top of the canopy during the previous week $W\ m^{-2}$

TLAI = tomato leaf area index

TLFRESP = tomato leaf dark respiration rate per unit ground area $mg\ CO_2\ m^{-2}\ s^{-1}$

TTRANS = tomato leaf transmission coefficient

TX = constant

TY = constant

Figure 9. Tomato leaf respiration rate integrated over the whole canopy (after Acock _et al._, 1978).

$$\mathrm{TPART1} = ((1. - \mathrm{TTRANS}) \times \mathrm{TUTILIZ} \times \mathrm{ENERGY}) + (\mathrm{TA} \times \mathrm{AVENRGY} \times CO_2)$$

$$\mathrm{TPART2} = \mathrm{TB} \times \mathrm{TUTILIZ} \times \mathrm{ENERGY} \times \mathrm{AVENRGY} \times \mathrm{TEXCOEF}$$

$$\mathrm{TPART3} = (\mathrm{TA} \times CO_2)/(\mathrm{TB} \times \mathrm{TEXCOEF})$$

$$\mathrm{TPART4} = \mathrm{EXP}(-\mathrm{TEXCOEF} \times \mathrm{TLAI})$$

$$\mathrm{TPNRATE} = \left[\mathrm{TPART3} \times \ln \left[\frac{\mathrm{TPART2} = \mathrm{TPART1}}{(\mathrm{TPART2} \times \mathrm{TPART4}) + \mathrm{TPART1}} \right] \times \mathrm{RATIOE} \times \mathrm{RATIOM} \right] - (\mathrm{TRESP} \times \mathrm{RATIOM})$$

where:

AVENRGY = average light flux density incident at the top of the canopy during the previous week $W\ m^{-2}$
CO_2 = CO_2 concentration $mg\ CO_2\ m^{-3}$
ENERGY = light flux density incident at the top of the canopy $W\ m^{-2}$
RATIOE = lesser value of RATIOP and RATIOT, used to scale down photosynthetic rate
RATIOM = adjustment to tomato photosynthetic rate due to age of the canopy
RATIOP = adjustment to photosynthetic rate due to leaf water potential differences from the optimum
RATIOT = adjustment to photosynthetic rate due to temperature differences from the optimum
TA = constant
TB = constant
TEXCOEF = tomato canopy extinction coefficient
TLAI = tomato leaf area index
TRESP = tomato total dark respiration rate per unit ground area $mg\ CO_2\ m^{-2}\ s^{-1}$
TTRANS = tomato leaf transmission coefficient
TUTILIZ = tomato leaf light utilization efficiency $mg\ CO_2\ J^{-1}$

Figure 10. Tomato photosynthetic rate integrated over the whole canopy (after Acock et al., 1978)

The photosynthetic rate function integrates single leaf responses over the entire canopy. Light attenuation through the canopy, and changes in leaf conductance to CO_2 transfer and dark respiration rate with depth in the canopy, are included (the latter in the leaf respiration function).

Photorespiration is not separately identified in the rate but is inherent in the light utilization coefficient. Dark respiration is subtracted from the gross rate. The photosynthetic rate therefore becomes negative when the solar radiation level is low or zero.

The use of the same respiration and photosynthesis functions for both species is reasonable due to their similar maximum net photosynthetic rates. Differences in species yield, canopy size, growth rates, etc., arise in the model from different carbohydrate partitioning strategies.

Three functions modify the photosynthetic rate. Functions describing the effect of temperature and leaf water potential are used to scale photosynthetic rate. The temperature function is derived from data of Kuiper (67).

$$\text{RATIOT} = .858 + .139\ \text{TEMP} - .0026\ (\text{TEMP})^2$$

where:

RATIOT = adjustment to photosynthetic rate due to temperature differences from the optimum

The value of RATIOT ranges between 1. and 0., with the optimum value of 1. at 26.5 C.

The leaf water potential function is derived from data of Brix (17).

$$\text{RATIOP} = 3.75 - 3.3 \log^{(\text{LFWPOTL})}$$

where:

RATIOP = adjustment to photosynthetic rate due to leaf water potential differences from the optimum.

The value of RATIOP ranges from 1. to 0., with the optimum value of 1. when LFWPOTL is less than 6.9 bar. When LFWPOTL reaches 14.5, RATIOP is .001.

Photosynthetic rate is scaled down by the lesser of these two ratios before respiration is subtracted. The same ratio is used for both species.

The third function is a maturity factor used only on tomato photosynthesis. This function scales down tomato photosynthetic rate after 50 simulation days (Figure 11).

$$\text{RATIOM} = 4.30 - 1.94 \log (\text{DAY})$$

where:

DAY = simulation days

This function is an approximation derived from field observations of the gross deterioration of the canopy. This was seen as senescence of the lower leaves, and fungal pathogen damage.

A second photosynthetic rate (STPNRATE) is computed using a solar radiation (ENERGY) value for 60% shade. The function is exactly the same as that described above. ENERGY is reduced to .4 times the input value from subroutine WEATHER. STPNRATE is used in photosynthate computations described below.

The above-ground interspecific and intraspecific competition is modeled by applying shading to the two species canopies. Donald (28), stated that light may be the only factor for which there is

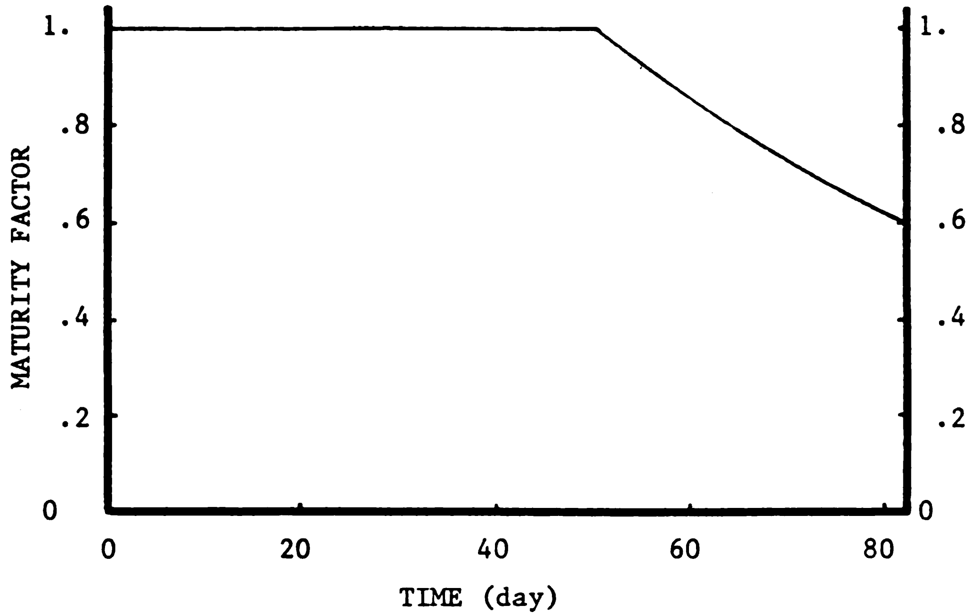


Figure 11. Tomato photosynthetic rate maturity function.

competition in crop situations with sufficient fertilization and water for rigorous growth. Both of those conditions are assumed here. Also, light is unique among crop growth inputs in that there is no reservoir of energy to draw upon during times of fluctuating or inadequate supply. This is different from water, whose bulk acts as a capacitor in smoothing out sporadic precipitation inputs.

The shading section of this subroutine computes bean canopy height from a regression on bean radius. This function was fitted to data collected by the author.

$$\text{BNHIGHT} = .0337 + .572 \times \text{BNRADB}^2$$

where:

BNHIGHT = bean canopy height m
BNRADB = bean canopy radius in the direction perpendicular to the row m

Bean shadow length is then the product of BNHIGHT and the shade data.

Tomato shading by the bean canopy is assumed to explain most of the interspecific competition (Figure 12). Although the bean and tomato canopies were observed to be of similar heights in the field in 1980, most of the tomato canopy was between zero and .15 m from the soil surface. Only occasional branches exceeded this height. By contrast, the bean canopy was dense over its full height, and formed an effective light screen. The model assumes that the low-lying, relatively open tomato canopy has no impact on light reaching the bean canopy. However, shading of the bean canopy by its counterpart on the opposite side of the hexagon is modeled. It is the bean-to-tomato and bean-to-bean shading which models the light competition.

The shading effect on tomato photosynthate production is computed by partitioning the tomato ground area. The photosynthetic rate

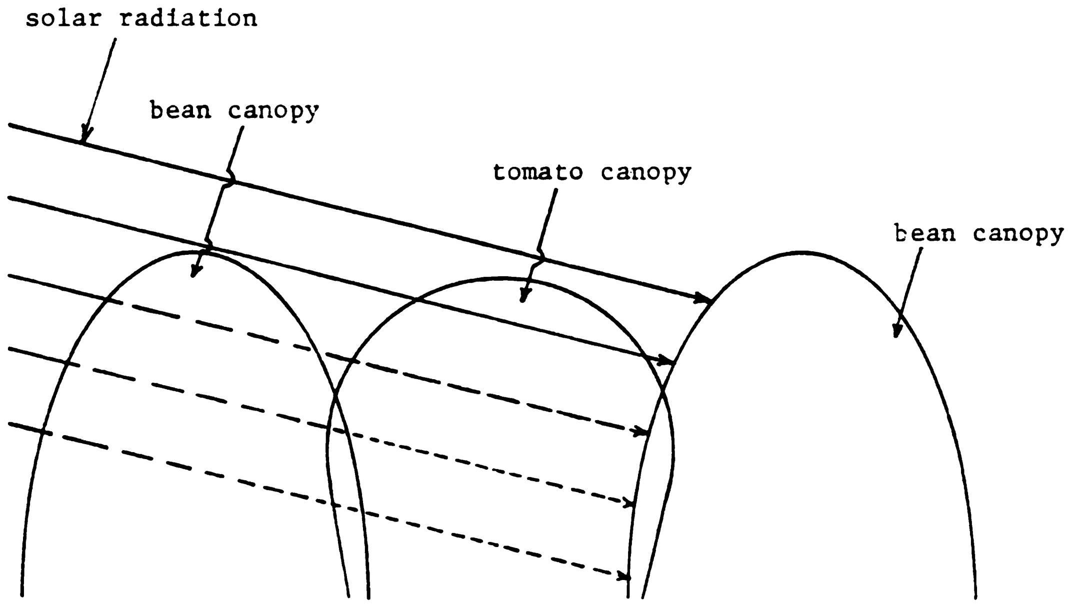


Figure 12. Shading of the tomato canopy by the dense bean canopy shown in a transverse section of a hexagon.

unit is mg CO_2 m^{-2} sec^{-1}. Ground area is, therefore, vital to total canopy photosynthate production. The model computes the fraction of the tomato ground area in shade. Early and late in the day this is 1. For several hours around solar noon it may be .1 to zero. As the bean canopy increases in height this shading effect becomes increasingly severe. Diminishing hexagon widths have the same effect. The relative fractions of tomato ground area in full sun and in shade are then used with full sun and shaded photosynthetic rates to compute total tomato plant photosynthate produced in that time step.

The bean shading effect is also computed by partitioning the bean ground area. However, due to the rather uniform vertical distribution of the bean canopy, the fraction shaded is computed differently (Figure 13). Bean shadow height $\underline{S}$ on its counterpart canopy across the hexagon is divided by total canopy height. The relative vertical fractions of full sun and shade are multiplied by bean ground area and used similarly as above in computing total canopy photosynthate. Due to the greater distance between the bean rows (i.e., hexagon sides) than between bean and tomato canopies, there is less of a shading impact on photosynthate production in bean.

Photosynthate produced in the 1 hr timestep is computed by multiplying full sun and shaded photosynthetic rates by the above fractions and summing the products. The subroutine output is g glucose per tomato and bean plant. The conversion from CO_2 to glucose uses the ratio of carbon content in CO_2 to that in glucose (111).

6. Carbohydrate Partitioning (Subroutines BNPART and TOMPART)

The logic in these two subroutines is identical. The difference between them lies in their equations.

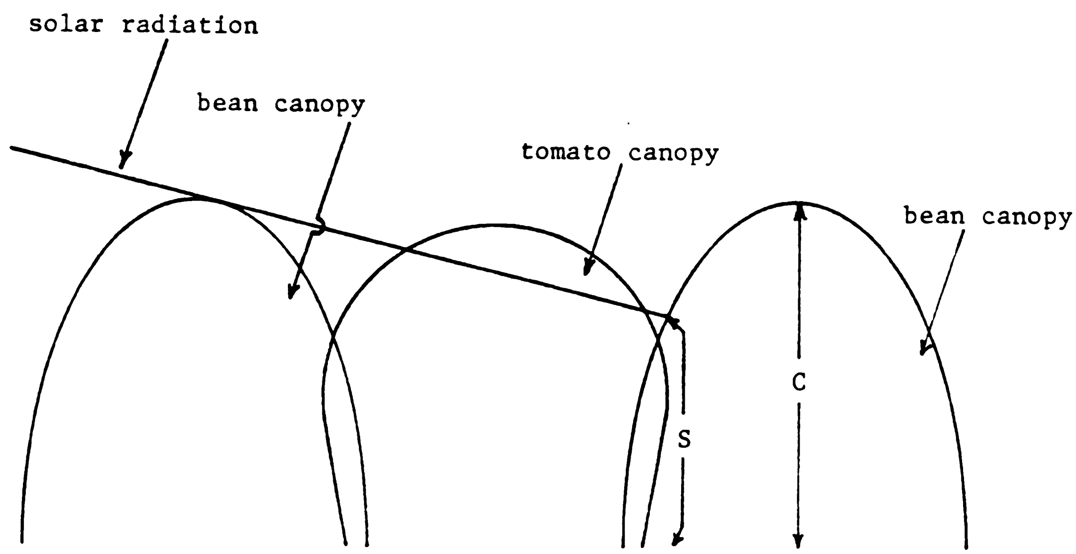


Figure 13. The fraction of shadow height S over canopy height C is used to partition bean ground area.

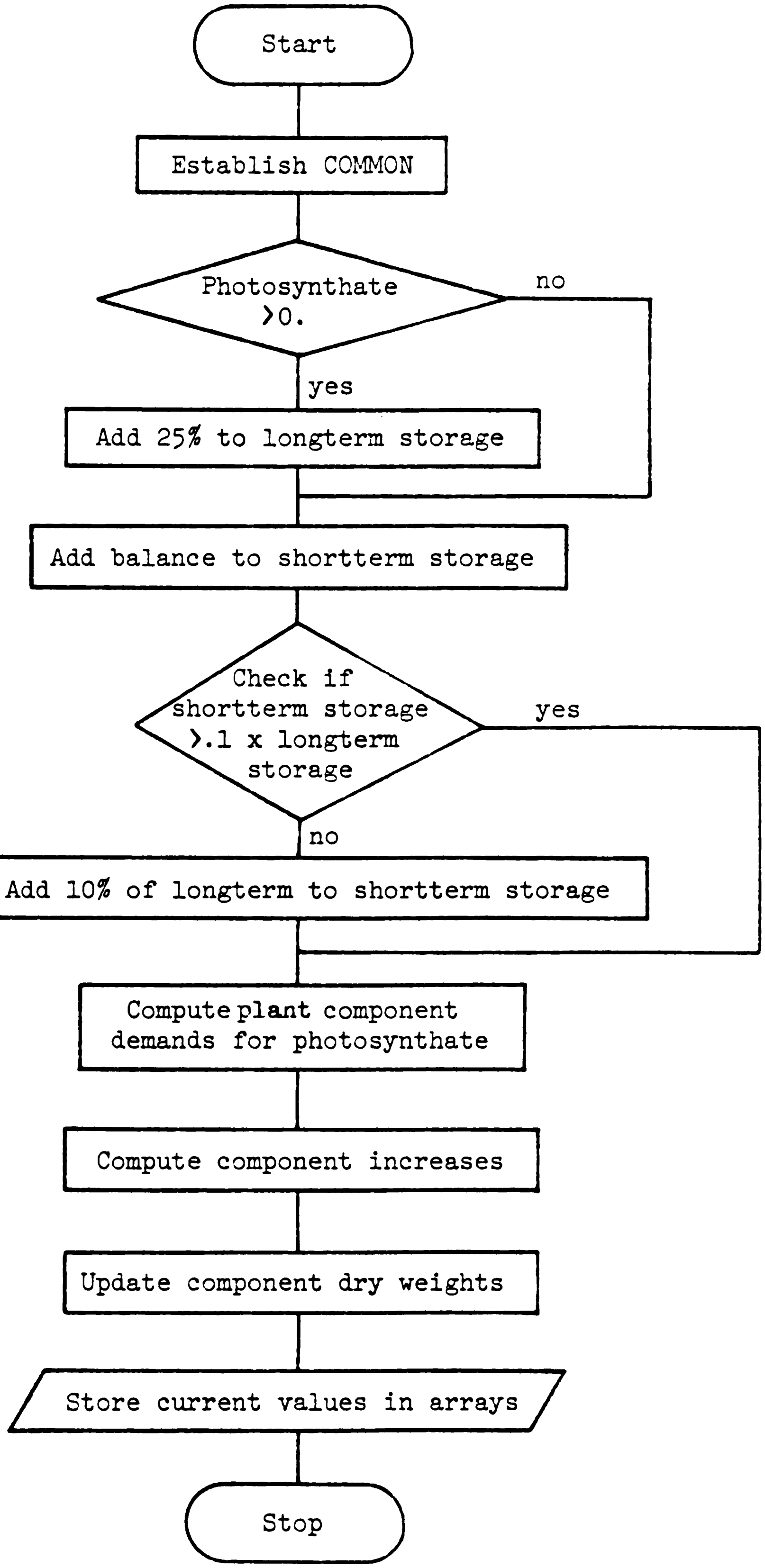
These subroutines partition the photosynthate produced in each timestep to state variables representing leaf, stem, root and fruit dry weight. (Figure 14).

Two carbohydrate pools are represented. Soluble carbohydrate is considered a short-term pool (CPOOL) available for immediate translocation. Sucrose is its major constituent. Insoluble carbohydrate is a long-term pool (CSTORE) available for slow release. Starch is its major constituent.

The carbohydrate input from subroutine PHOTO may be positive (e.g., full sun) or negative (e.g., night hours). If it is positive then 25% is retained in CSTORE and 75% is added to CPOOL. If CPOOL is greater than 10% of CSTORE then 67% of CPOOL is translocated or available for structural growth in the leaf. This means that up to 50% of new carbohydrate is available for translocation in that timestep. If CPOOL is less than 10% of CSTORE (e.g., at night) then CPOOL is made up to 10% by transfer of dry matter out of CSTORE. The full amount transferred is then translocated.

This allocation ratio is based on work with several species. Ho (51) found in tomato that the rate of carbon export in leaves with high carbon fixation rates was 60-66% of the rate of carbon fixation. This export rate was less at lower carbon fixation rates. Hofstra, *et al.*, (52) found the amount translocated after 1 hr to be 38% in tomato, 50% in sunflower, 53% in sorghum and 32% in castor bean. Pearson (95) found the rate in broad bean to be 35%. From these data a translocation rate of 50% of new photosynthate was assumed for both species.

Figure 14. System diagram of Subroutine BNPART and TOMPART


Start
Establish COMMON
Photosynthate
>0.
no
yes
Add 25% to longterm storage
Add balance to shortterm storage
Check if
shortterm storage
>.1 x longterm
storage
yes
no
Add 10% of longterm to shortterm storage
Compute plant component
demands for photosynthate
Compute component increases
Update component dry weights
Store current values in arrays
Stop

The partitioning of carbohydrate to plant components is a major problem in plant modeling. Two general approaches have been taken. First, functions have been fitted to dry weight data accumulated over the growing season. This descriptive approach reveals nothing about the mechanism of partitioning and is somewhat season-specific. An example is the perennial ryegrass model of Sheehy, et al., (109). This approach is also used in MULTICROP. Regression equations of dry weight data are used in this subroutine to partition both bean and tomato photosynthate.

The second approach is to attempt descriptions of carbohydrate flow rates between plant parts. Holt, et al., (53) used this approach in an alfalfa model, but scaled the maximum rates back with "maturity factors" which are again descriptive. A more complex model devoted entirely to dry matter distribution in sugar beet uses a primarily mechanistic approach, with partitioning rates controlled by the internal water supply and internal photosynthate supply (35). The most complex attempt to describe partitioning mechanistically is that of Thornley (117).

The descriptive approach was used in this model due to its relative simplicity and reasonable accuracy. Further expansion and refinement of the model would benefit from inclusion of a mechanistic partitioning section.

The component demand functions for carbohydrate used in partitioning are regressions fitted to field data (Figure 15). An exception is that for roots. The root : shoot ratio is an extremely complicated relationship to which an entire model has been devoted (18).

Figure 15. Equations used to partition carbohydrate between plant parts.

Bean demand functions:

$$\text{leaf demand} = 10^{(-.407 + .0425\ \text{DAY})}$$

$$\text{stem demand} = 10^{(-.84 + .0466\ \text{DAY})}$$

$$\text{fruit demand} = 156.3 - 8.73\ \text{DAY} + .122\ \text{DAY}^2$$

if DAY<37, fruit demand = 0.

root demand

if DAY<20, root demand = .16 (stem + leaf + fruit demands)

21<DAY<48, root demand = .11 (stem + leaf + fruit demands)

DAY>49 root demand = .08 (stem + leaf + demands)

Tomato demand functions

$$\text{leaf demand} = .882 + .308\ \text{DAY} + .0269\ \text{DAY}^2$$

$$\text{stem demand} = 1.17 + .274\ \text{DAY} + .0161\ \text{DAY}^2$$

$$\text{fruit demand} = 47.3 - 5.10\ \text{DAY} + .138\ \text{DAY}^2$$

if DAY<19, fruit demand = 0.

root demand

if DAY<20, root demand = .16 (stem + leaf + fruit demands)

21<DAY<48, root demand = .11 (stem + leaf + fruit demands)

DAY>40, root demand = .08 (stem + leaf + fruit demands)

where:

DAY = days after commencement of the simulation

A simple method based on the data of Richards, et al., (103) and Gulmon, et al., (40) is used in this model. Root:shoot ratios ranging from .16 in young plants to .08 in older plants are used. No attempt to modify these ratios in response to environmental factors is made in the model.

The component demands are balanced so that their total is 1. The carbohydrate available is allocated according to this balance, and reduced by 25% before being added to the component cumulative dry weights. Data by Penning de Vries, et al., (97) indicate a conversion efficiency of 75% in producing plant structure from glucose, assuming an adequate supply of NH_3 and minerals. This value is also used elsewhere (53).

The outputs of these subroutines are cumulative values of leaf, stem, root and fruit dry weight for bean and tomato plants.

7. Bean and Tomato Canopy Growth (Subroutine CANOPY)

This model converts leaf dry matter to leaf area and simulates bean and tomato canopy growth. Four different modes of bean canopy exapansion are modeled (Figure 16).

Leaf dry matter is converted to leaf area by a regression of ground area on leaf dry weight. Both functions are derived from growth data collected in 1980.

BLFAREA = .0241 BDRYLF -.0062

TLFAREA = .0243 TDRYLF -.0143

where:

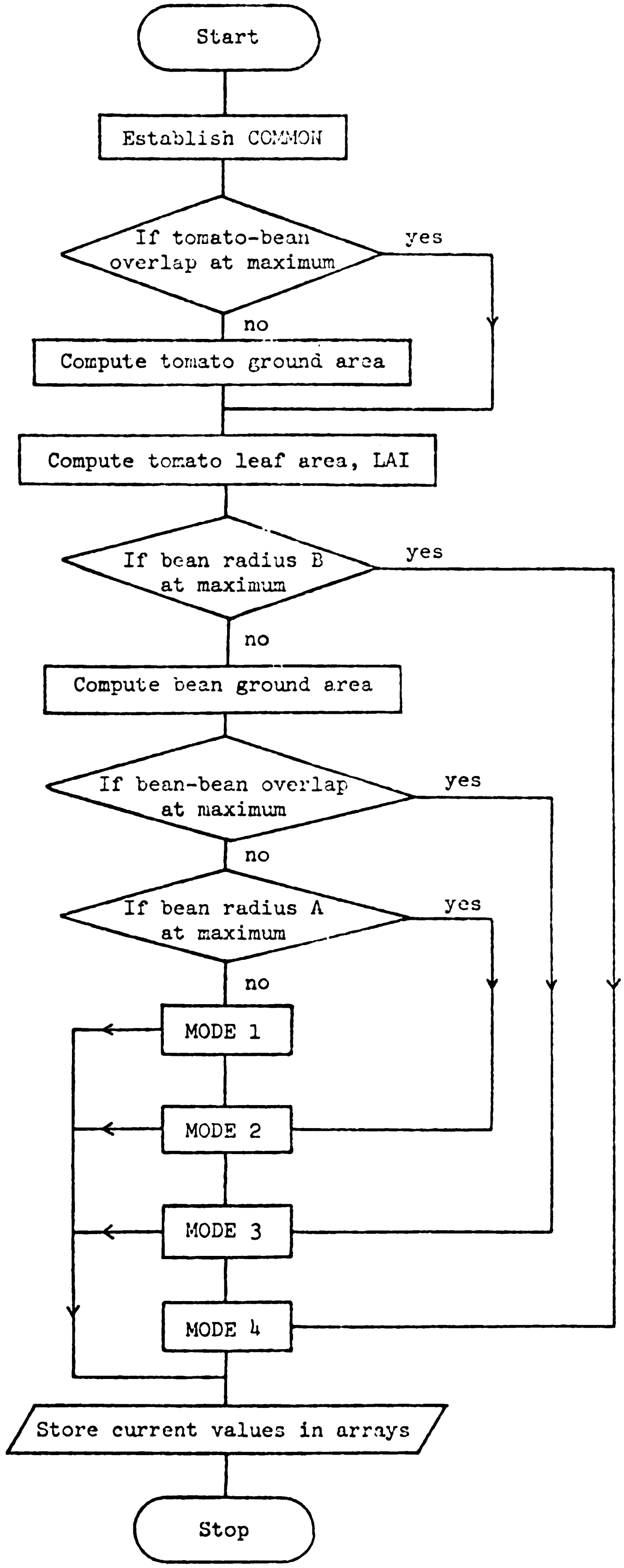
BDRYLF = bean leaf dry weight g

BLFAREA = bean leaf area m^2

TDRYLF = tomato leaf dry weight g

TLFAREA = tomato leaf area m^2

Figure 16. System design of Subroutine CANOPY


Start
Establish COMMON
If tomato-bean overlap at maximum
yes
no
Compute tomato ground area
Compute tomato leaf area, LAI
If bean radius B at maximum
yes
no
Compute bean ground area
If bean-bean overlap at maximum
yes
no
If bean radius A at maximum
yes
no
MODE 1
MODE 2
MODE 3
MODE 4
Store current values in arrays
Stop

Bean and tomato canopy ground areas are also functions of their respective leaf dry weights. The functions are regressions derived from 1980 field data.

$$BGRAREA = 10.^{(-1.79 + .779 \log BDRYLF)}$$
$$TGRAREA = 10.^{(-1.62 + .685 \log TDRYLF)}$$

where:

BGRAREA = bean canopy ground area m^2
TGRAREA = tomato canopy ground area m^2

Tomato canopy ground area is assumed to be circular. Its radius is limited by either an absolute limit when no bean canopy is contacted, or a maximum tomato-bean overlap of .1 m. Tomato LAI is computed from leaf and ground areas.

Bean canopy ground area changes shape during the season. Its maximum radius in the direction perpendicular to the row is a function of hexagon size, derived from 1980 field data.

$$MBNRADB = .327 + .632 \log TTDIST$$

where:

MBNRADB = maximum bean radius perpendicular to the bean row m
TTDIST = tomato-tomato distance (hexagon width) m

Bean canopy growth simulation is in 4 modes (Figure 17).

a. Mode 1.

Initial bean canopy growth is assumed to be circular. The canopy radii parallel to the row (BNRADA) and perpendicular to the row (BNRADB) are equal. The radius is derived from the ground area. No bean-bean overlap occurs.

b. Mode 2

Early overlap of neighboring bean canopies occurs in

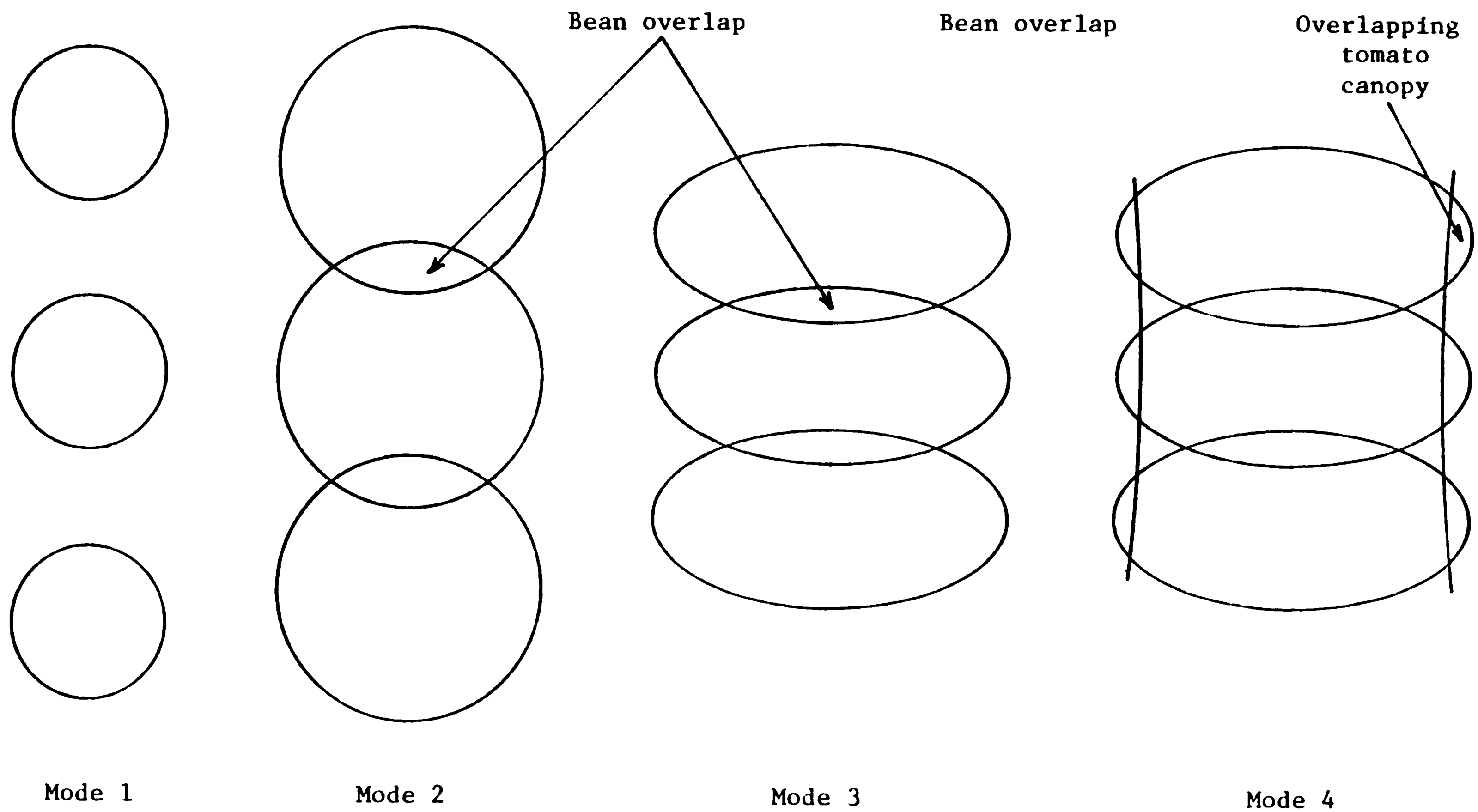


Figure 17. Bean canopy simulation modes.

Mode 2. Circular canopy expansion continues until a maximum overlap of .05 m occurs. The duration of the simulation in Modes 1 and 2 is highly dependent upon bean-bean distance.

The overlap of neighboring bean canopies adds to LAI of the single plant modeled. The model simulates this by computing the overlap area which is approximated as an ellipse (Figure 18). Dry leaf weight of the overlap area contributed by the neighboring plant is computed and added to the dry leaf weight of the modeled plant. Leaf distribution in the canopy is not evenly spread over the plant ground area. The LAI at the canopy edge is less than in its center. Therefore, the LAI of the neighboring plant added in the overlap is reduced by two-thirds.

This method of increasing LAI due to the overlap is also followed in Modes 3 and 4.

c. Mode 3.

Upon expansion of BNRADA to its defined limit, the canopy changes shape to an ellipse. Further advance in BGRAREA is in the BNRADB direction.

d. Mode 4.

Elliptical growth continues until the maximum tomato-bean overlap is just exceeded. In Mode 4, BGRAREA expansion has terminated and BDRYLF is added to the ground area occupied.

Outputs of this subroutine are LAI and ground area.

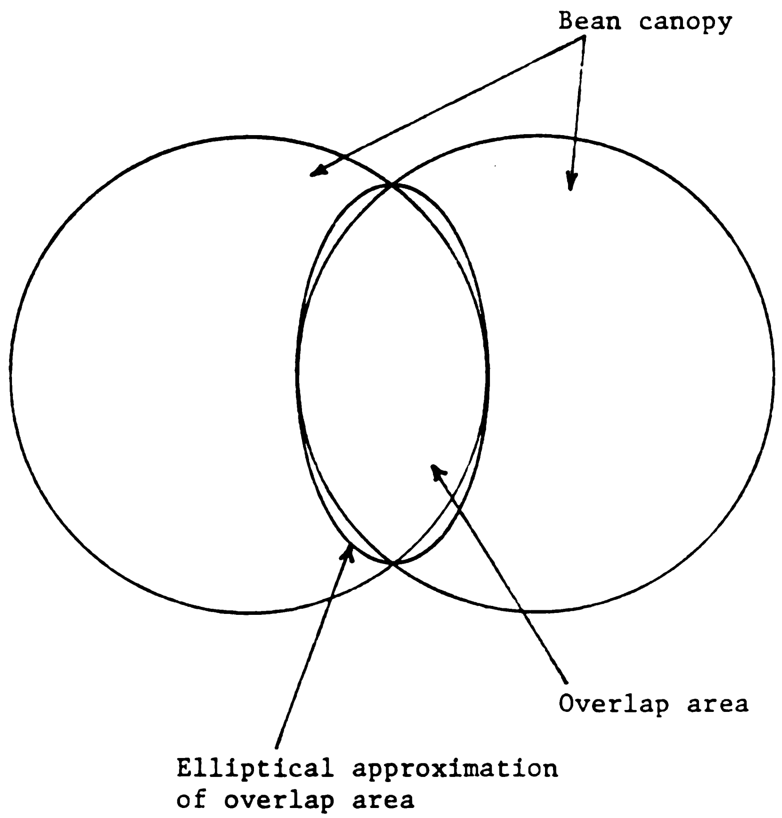


Figure 18. Bean canopy overlap with approximating ellipses.

8. Bean and Tomato Yield (Subroutine YIELD)

Bean and tomato fruit yields are computed in this subroutine. Plant populations are computed and various yield descriptions given (Figure 19).

Fresh fruit is computed from fruit dry weight using regression functions derived from 1980 field data.

TFRFRT = (50.5 + 18.9 TDRYFR) /1000.

BFRFRT = .014 BDRYFR

where:

BDRYFR	= bean fruit dry weight	g
BFRFRT	= bean fruit fresh weight	kg
TDRYFR	= tomato fruit dry weight	g
TFRFRT	= tomato fruit fresh weight	kg

Hexagon area, circumference and number per hectare are computed. This allows computation of bean and tomato populations.

Yield for each species and their sum is computed per hexagon, m^{-2} and hectare. These are the subroutine outputs.

9. Simulation Termination

Upon completion of the required number of iterations, the program prints variable values as initially requested. The operator is asked if further simulations are intended. If not, the program immediately terminates. A positive response causes a return to an early point in DRIVER and initialization of variable values. The operator may then run the program again.

E. DATA COLLECTION FOR THE MODEL

1. Plant Growth Curves

Growth curves were required for both species to partition carbohydrates in the model. Plants were grown as non-competing

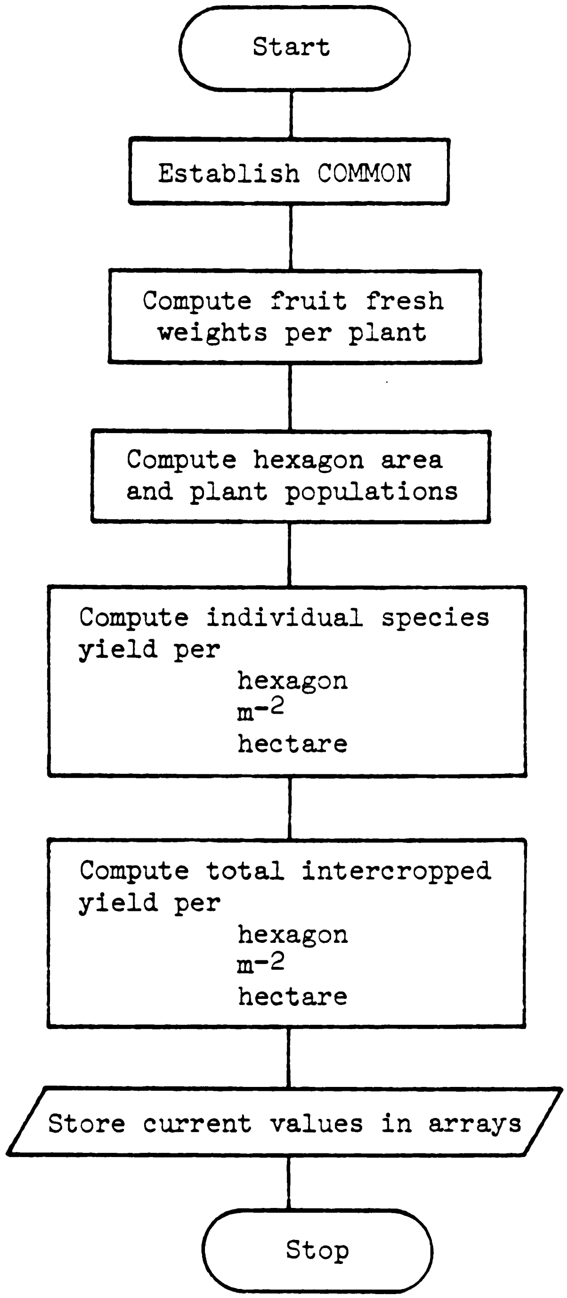


Figure 19. System diagram of Subroutine YIELD

individuals and harvested at regular intervals throughout the 1980 season.

Tomato transplants (cv. PikRed) were started in VSP Peat Lite Mix in cell packs on April 28, 1980. After hardening-off, they were transplanted into the field on May 25. The Capac loam soil was fertilized with 170 kg P_2O_5, 170 kg K_2O and 113 kg N per hectare, and sprayed with .85 kg per hectare Treflan 1 week prior to planting. A 250 ml portion of 12:48:8 starter solution and .078% Chlordane was poured in each hole before putting in the transplant. The plants were not staked. Cultivation following transplanting was by hoe.

A hexagonal planting design was used, which placed the plants 1 m from each neighbor (Figure 20). Interplant competition was virtually absent at this distance. A total of 100 plants were planted.

Bean seeds (cv. Bush Blue Lake) were planted in the field on June 5. The field conditions were as above with the exception of the starter solution and Chlordane. Three seeds were planted in each of 100 positions in a .8 m hexagonal grid (Figure 20). The germinated seedlings were thinned to 1 plant per position.

Entire plants of both species were harvested at 4 day intervals throughout the growing season, commencing June 23. Five randomly selected plants of each species were measured for height and canopy diameter in 2 directions, at each harvest date. The plants were cut off at ground level, placed immediately in individually sealed plastic bags, and transported to a 2 C refrigerator.

Leaf area was measured in a Lycor leaf area meter for each bean plant for the first 4 weeks. Leaves were removed from the petioles and their areas were measured. The plant parts were then dried and

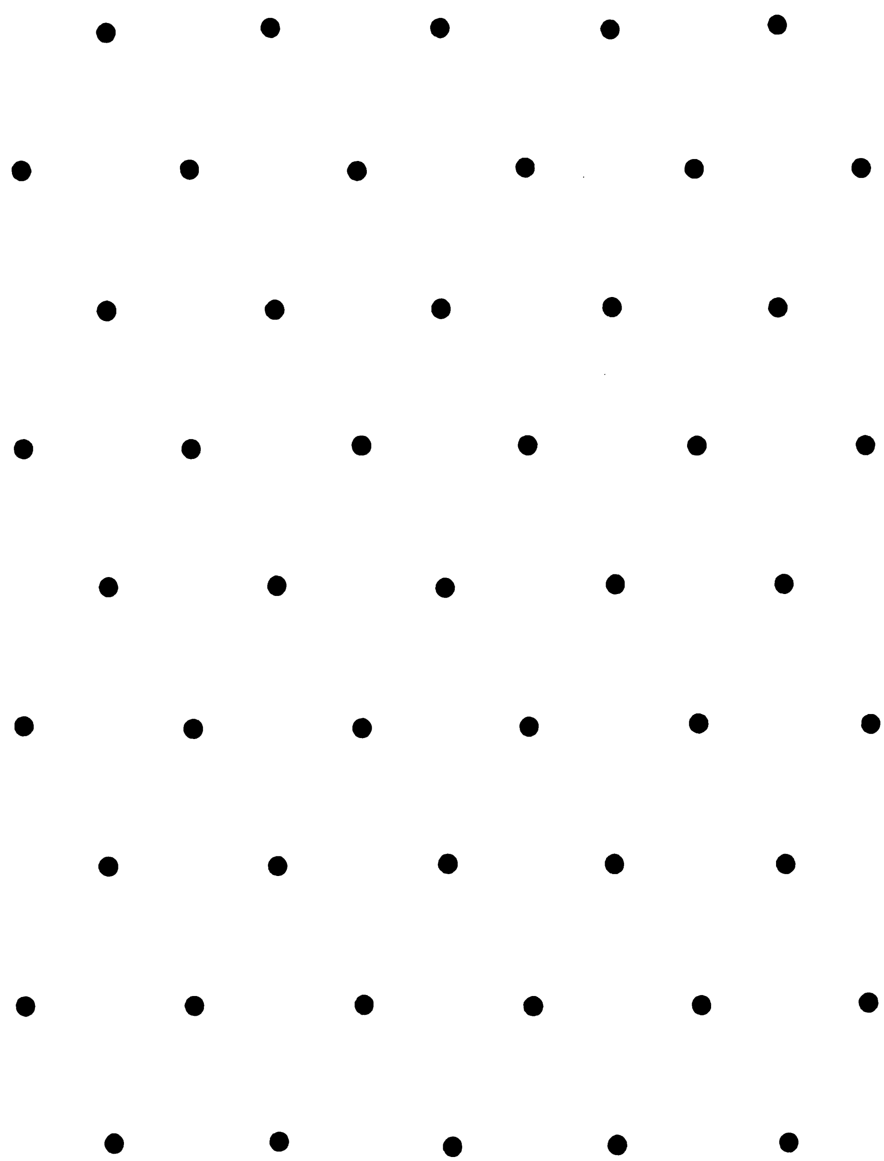


Figure 20. Planting design for bean and tomato growth curve data.

weighed. After 4 weeks the plants were large and this operation became prohibitively time-consuming.

Tomato leaf area was measured similarly. After 2 weeks the number of plants measured was reduced to 1 due to the canopy size.

All harvested plants were oven-dried at 70 C in a forced-air oven. Space in this oven was unavailable during the latter half of the season. During this time plants were stored at -5 C and dried as above when space became available.

With the exception of those plants dissected for leaf area measurement, the plants were dried intact and separated into leaf, stem and fruit components prior to weighing. Curves were fitted to the data and plots made on the MINITAB interactive statistical analysis system (98).

2. Fruit Fresh Weight : Dry Weight Ratios

Three 1.5 kg fresh samples of bean fruits were dried to obtain a fruit fresh weight : dry weight ratio. These samples contained a range of fruit sizes typical of those found in harvests from the validation experiments described later.

Three samples each of 10 tomato fruit were dried to obtain their fresh weight : dry weight ratio. Each sample was composed of a different fruit ripeness stage ranging from mature-green to firm-ripe.

3. Soil Water Content

Gravimetric soil water measurements were taken on June 24 (one day after model commencement) and July 16. A .1 m diameter hand auger was used to take soil samples from each .1 m layer to a depth of 1.5 m. The samples were taken from 5 different positions across the field on each date.

Samples were removed from the auger and immediately enclosed in a sealed plastic bag. Their gravimetric water content was determined by oven drying approximately 250 g samples at 70 C.

4. Preliminary Hexagon Trial

A preliminary experiment was performed during the summer of 1979 to determine suitable hexagon sizes and bean spacings for the model.

Three plots were planted with tomato plants placed hexagonally and encircled by hexagonal bean rows (Figure 21). Each harvested tomato plant and its associated bean hexagon was completely surrounded by guard hexagons. Each of the three plots was identical except for the hexagon width, which was .8, 1., or 1.2 m per plot. Within each plot, the harvested hexagons were planted with beans .05, .1, or .15 m apart within the row. Three hexagons were randomly allocated to each bean planting distance, giving a total of 9 harvested hexagons per plot.

Soil type and field preparation were as above. The beans were hand-harvested twice, and the plants were removed from the field after the second harvest. The tomatoes were hand-harvested 5 times.

These planting distances were found to be suitable for the simulation. Reasons for this are discussed in the Results and Discussion section. The hexagon dimensions and bean populations were retained for use in the 1980 validation experiment.

F. FIELD VALIDATION

Two field validation experiments were performed in 1980. Bean and tomato plants were grown in hexagons with various plant populations and bean planting dates.

● = harvested tomato plant and associated bean hexagon

○ = guard tomato plant and associated bean guard row

▬ = bean row

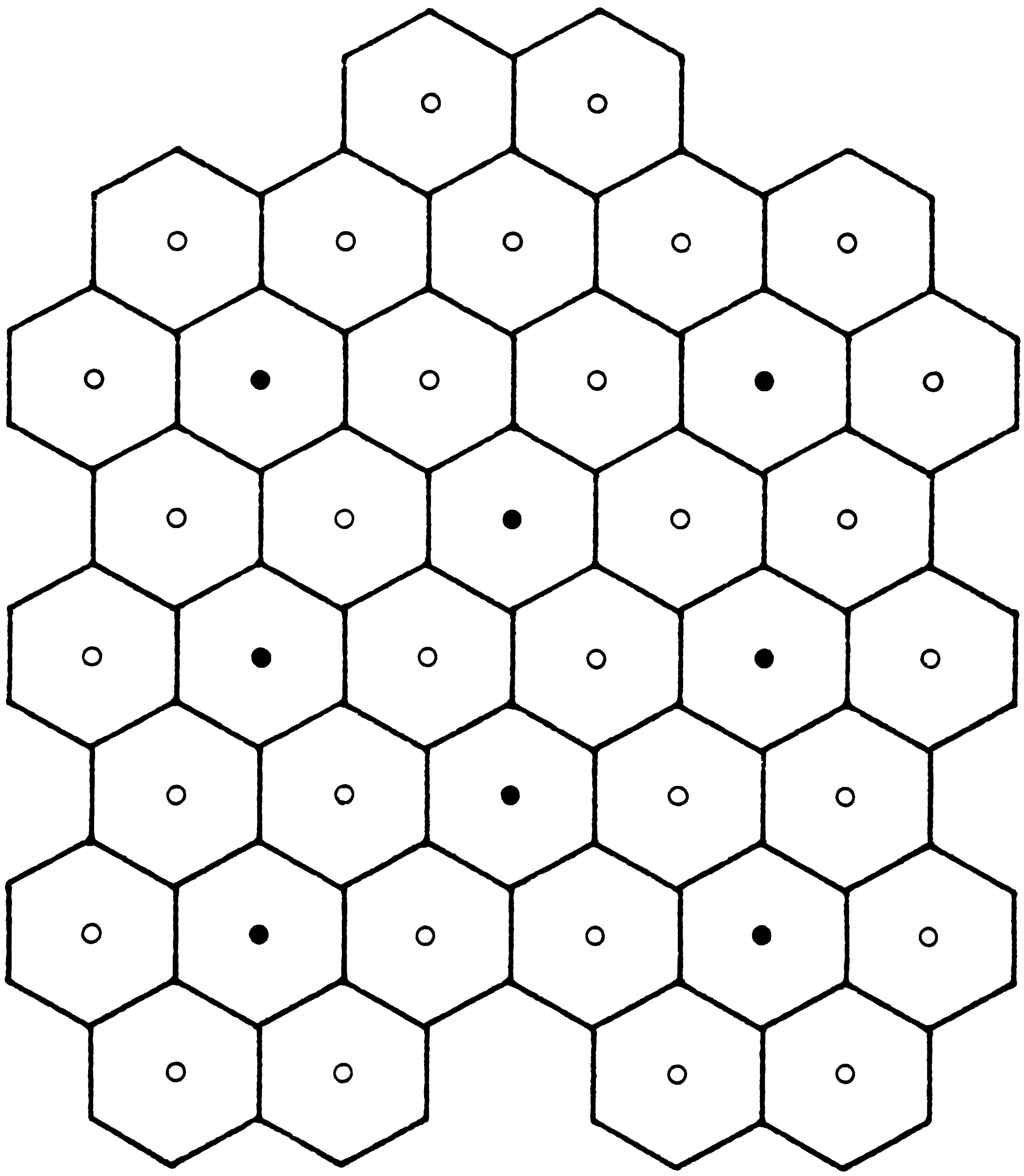


Figure 21. Plot design for preliminary spacing experiments.

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1. Spacing Experiment

A replicated spacing experiment was conducted to test the hypothesis that hexagon size and bean population had no effect on individual species yields. The design was a split plot in a 3 x 3 factorial randomized block design.

The main plots were hexagon widths of .8, 1. and 1.2 m. Since hexagons of differing widths cannot combine into a single matrix, whole plots were assigned to each main plot level (Figure 22). Split plots were 3 bean-bean planting distances at .05, .10 and .15 m. Three subsamples of each subplot were planted (Figure 22).

All main plots were of an identical design (Figure 23). Nine hexagons with bean and tomato for harvesting formed the center of each plot. At one end were 17 tomato plants without encircling bean hexagons. Three of these were harvested. At the opposite end were bean hexagons without tomato. Each harvested hexagon of this group had a different bean spacing.

A difficulty with the hexagonal design is the large number of guard hexagons required. This was minimized by bisecting the hexagon side which linked neighboring hexagons with different bean planting distances (Figure 24). Any error introduced was uniformly applied across the plot and assumed to be negligible.

Field preparation and planting details were as stated above. Hand cultivation and harvesting were practiced. This and all other experiments received 3 overhead irrigations. A total of .065 m of water was applied.

Beans were harvested and weighed on August 5 and 12. All the bean plants in the harvested hexagons and the guard rows were

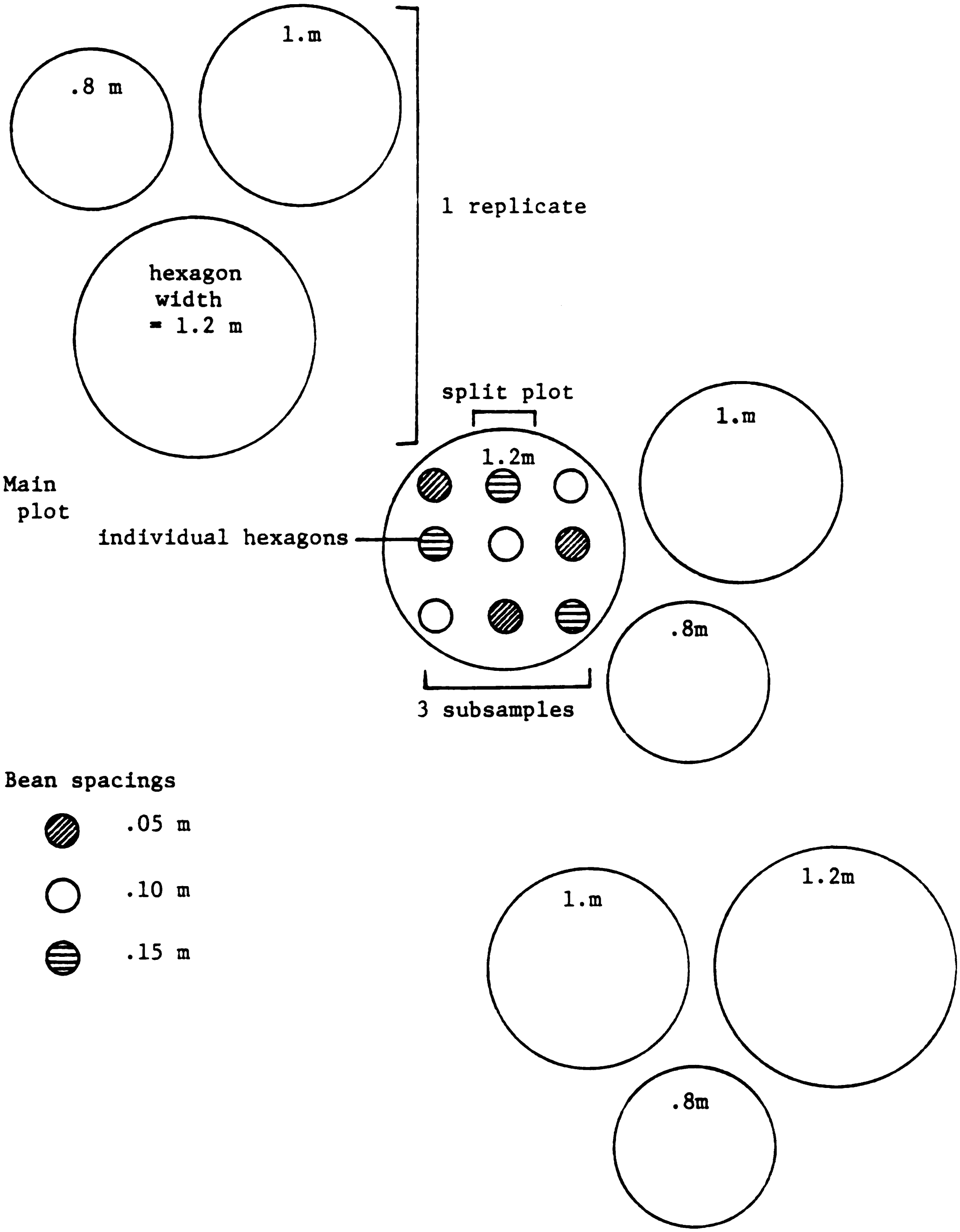
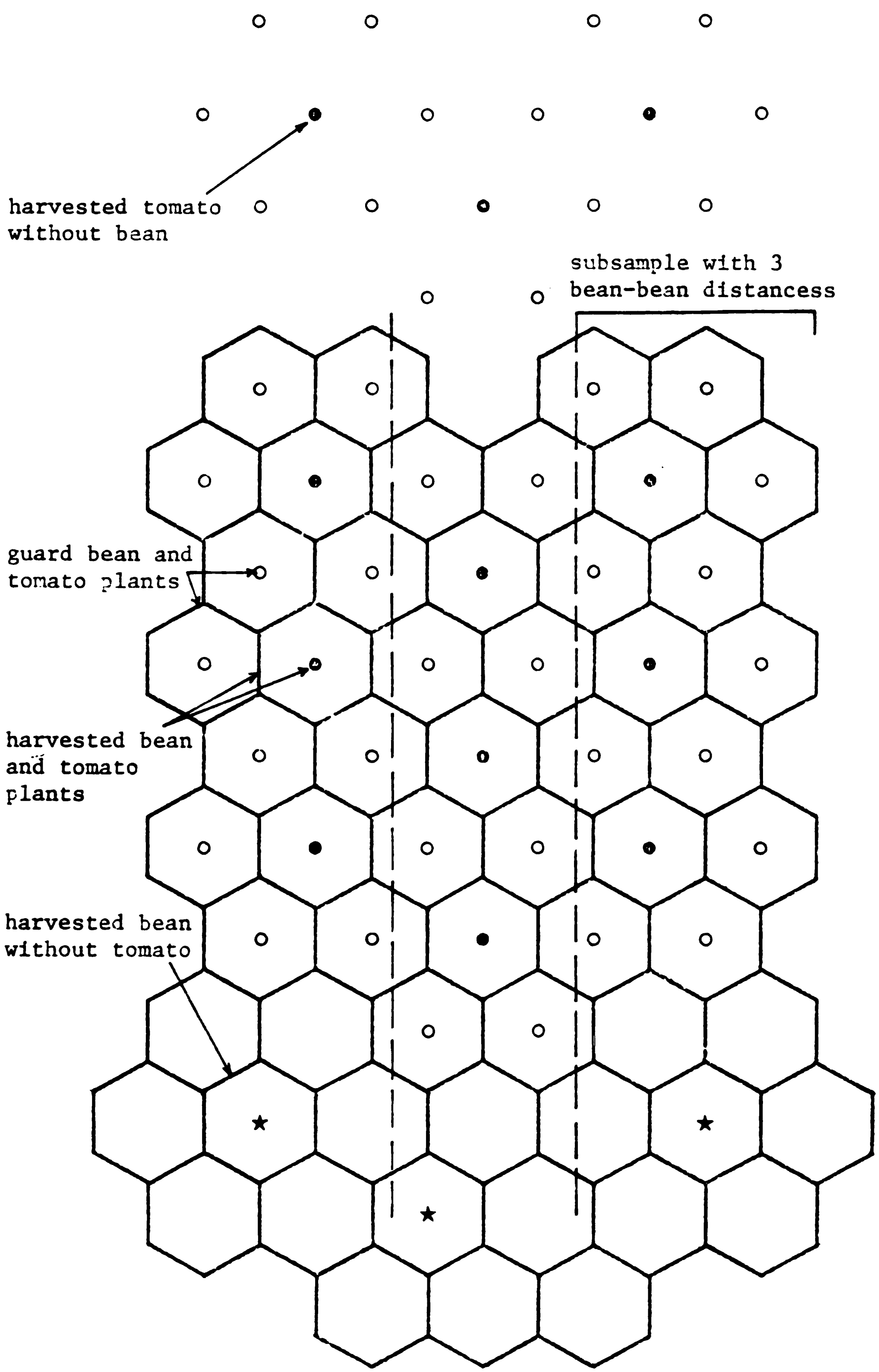


Figure 22. Schematic representation for spacing experiment.

Figure 23. Individual main plot design for spacing experiment.



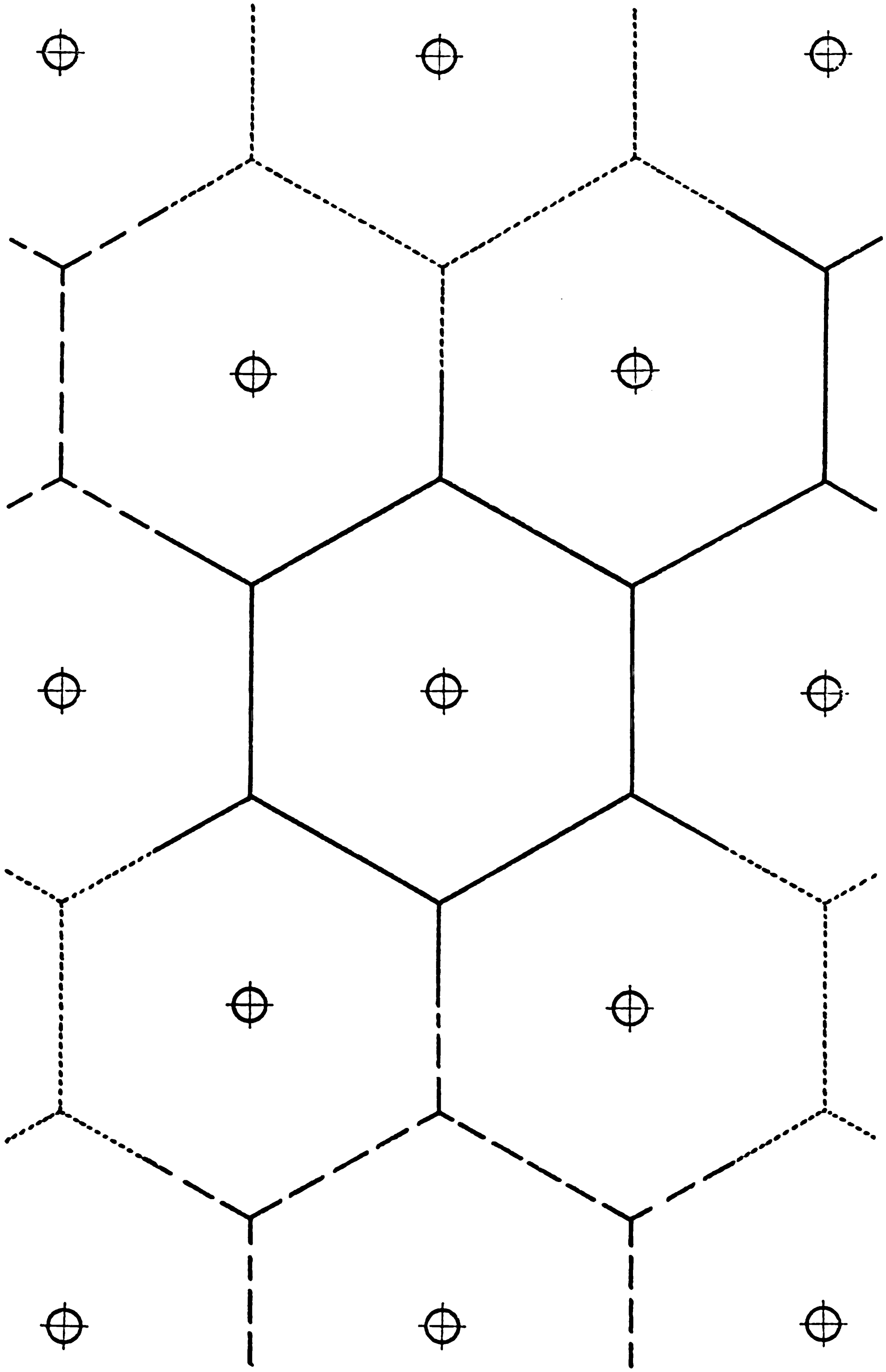
harvested tomato without bean
subsample with 3 bean-bean distancess
guard bean and tomato plants
harvested bean and tomato plants
harvested bean without tomato

Figure 24: Segment of spacing experiment plot showing interlocking of hexagons planted to different bean-bean distances in the row.

= beans planted .05 m apart

= beans planted .10 m apart

= beans planted .15 m apart



removed from the field during the second harvest. Care was taken during the harvests to minimize spatial dislocation of the two canopies. Heights and widths of the two species' canopies were measured prior to the first harvest.

Tomatoes were harvested at the 'breaker' stage on September 4. A second harvest on September 10 removed all remaining fruit regardless of size and ripeness. Reported yields are totals of all fruit from both harvests.

Analysis of variance and Duncan's multiple range test were performed on the yield data (115).

2. Planting Date Experiment

A replicated planting date experiment was conducted to test the hypothesis that varying the bean planting date would have no effect on individual species yield. The design was a split-split plot in a 3 x 3 x 3 factorial randomized block design (Figures 25,26).

The main plots were hexagon widths of .8, 1. and 1.2 m. Split plots were bean-bean planting distances of .05, .1 and .15 in. The split-split plots were 3 planting dates. All the tomato transplants were set on May 25. The first bean planting was on June 5, with the others following on July 9 and August 8. Harvests of the first beans planted were on August 5 and 12. The second planting was harvested on September 5 and 11. Bean plants in the third planting date section were frozen and no yield data were collected.

Statistical analysis was performed as for the spacing experiment.

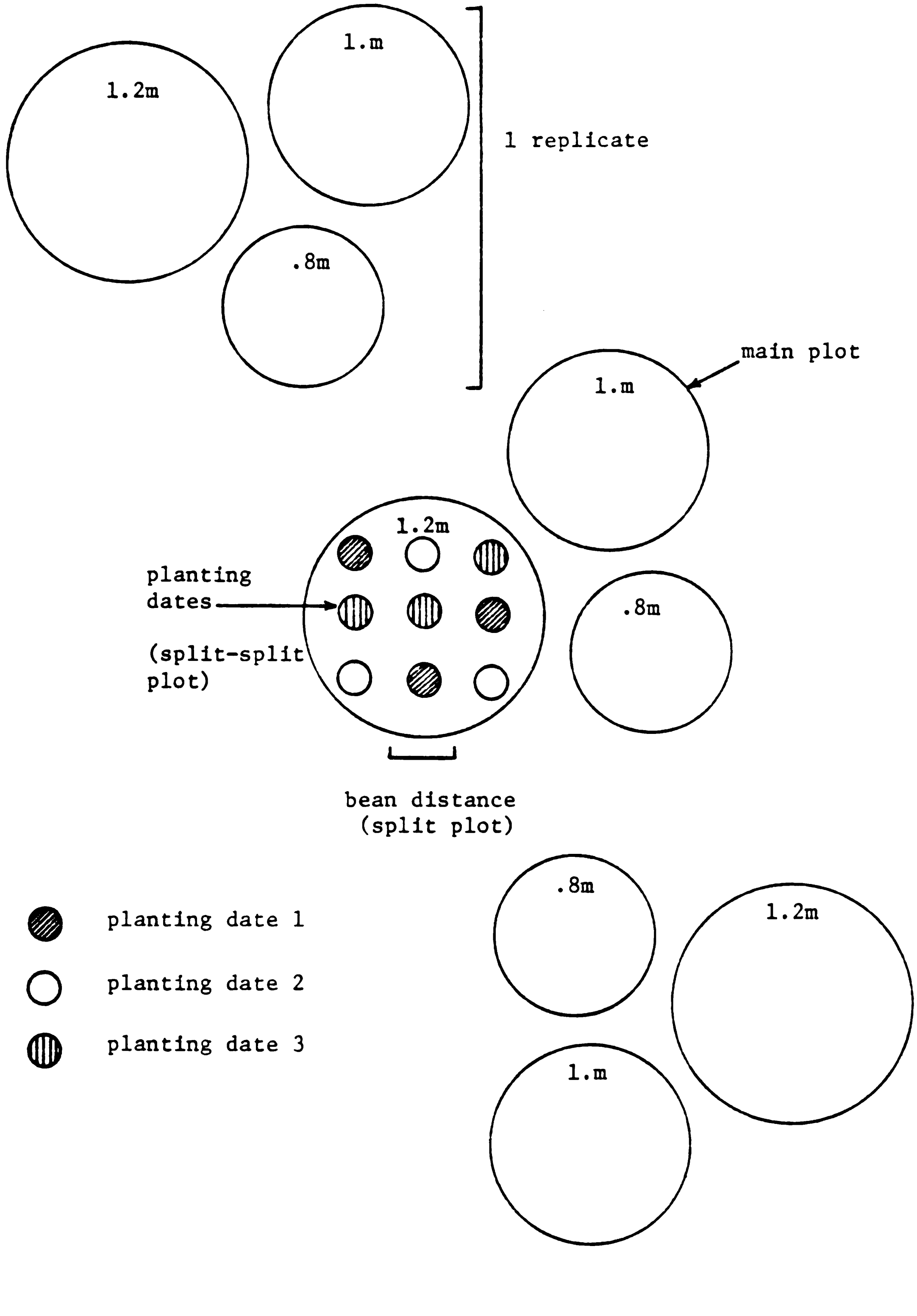


Figure 25. Schematic representation for planting date experiment.

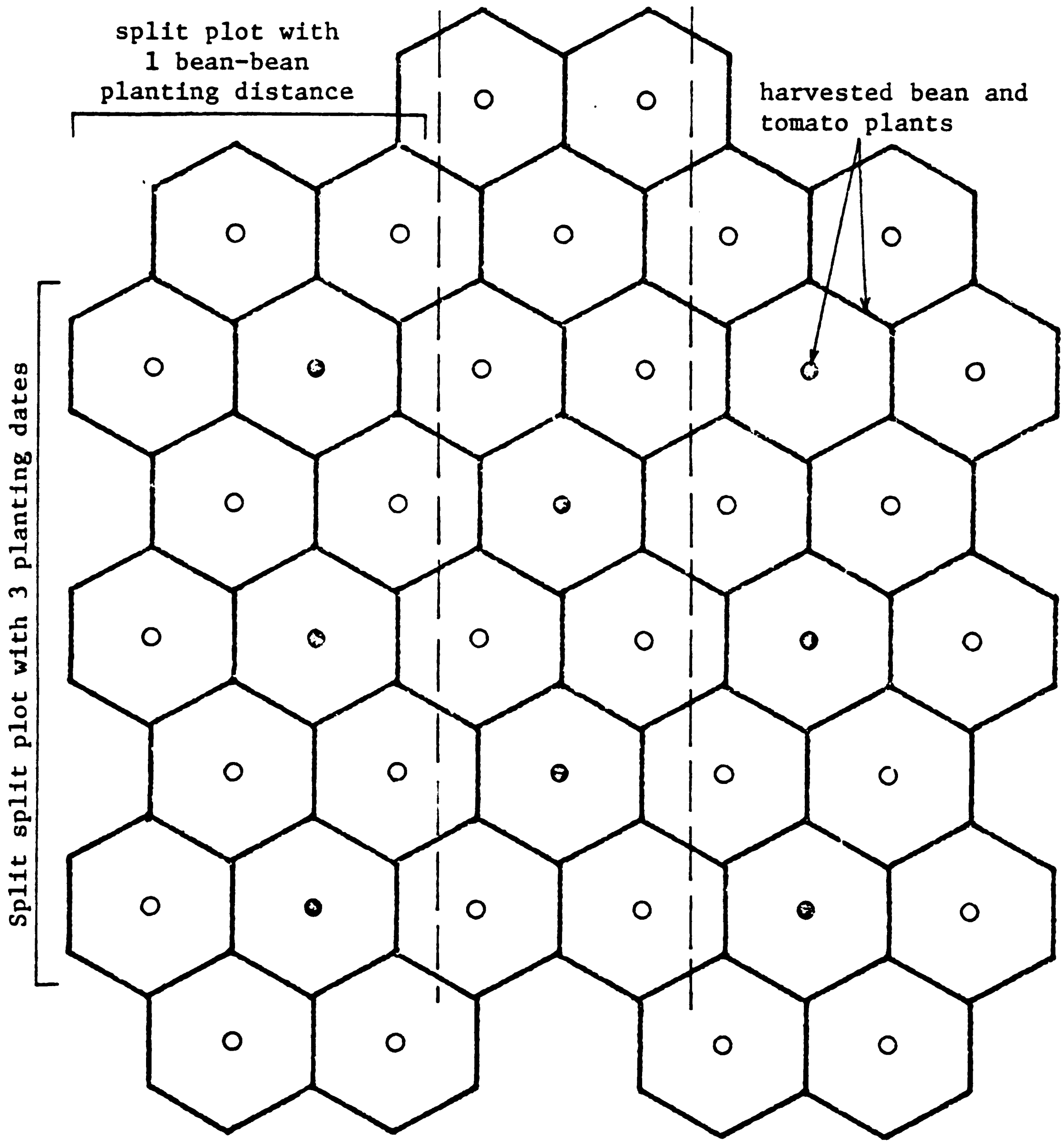


Figure 26. Individual main plot design for planting date experiment.

G. MODEL SIMULATIONS

Simulations were performed to ascertain the model's response to planting distances of both species. Tomato planting distance (hexagon size) was held constant at .8 m while bean-bean distance was varied between .05 and .15 m. The tomato distance was then increased to 1. and 1.2 m and the process was repeated.

This series of simulations was repeated with the bean planting date moved later into the season. Simulations were run with planting distances in all combinations of .8, 1. and 1.2 m between tomato plants and .05, .10 and .15 m between bean plants.

The third series of simulations was to repeat the first series with weather data from two other years. A total of 3 years' weather data were used.

Finally, tomato-tomato distance was increased to 5 m and bean-bean distance to 2 m. This simulation was equivalent to isolated tomato and bean plants.

RESULTS AND DISCUSSION

A. DATA COLLECTION

1. Plant Growth Curves

The bean and tomato growth curve data appear with their fitted curves in Figures 27-32. The data show increasing leaf and stem dry weight up to the final harvest. This is because the plants were still vegetatively expanding.

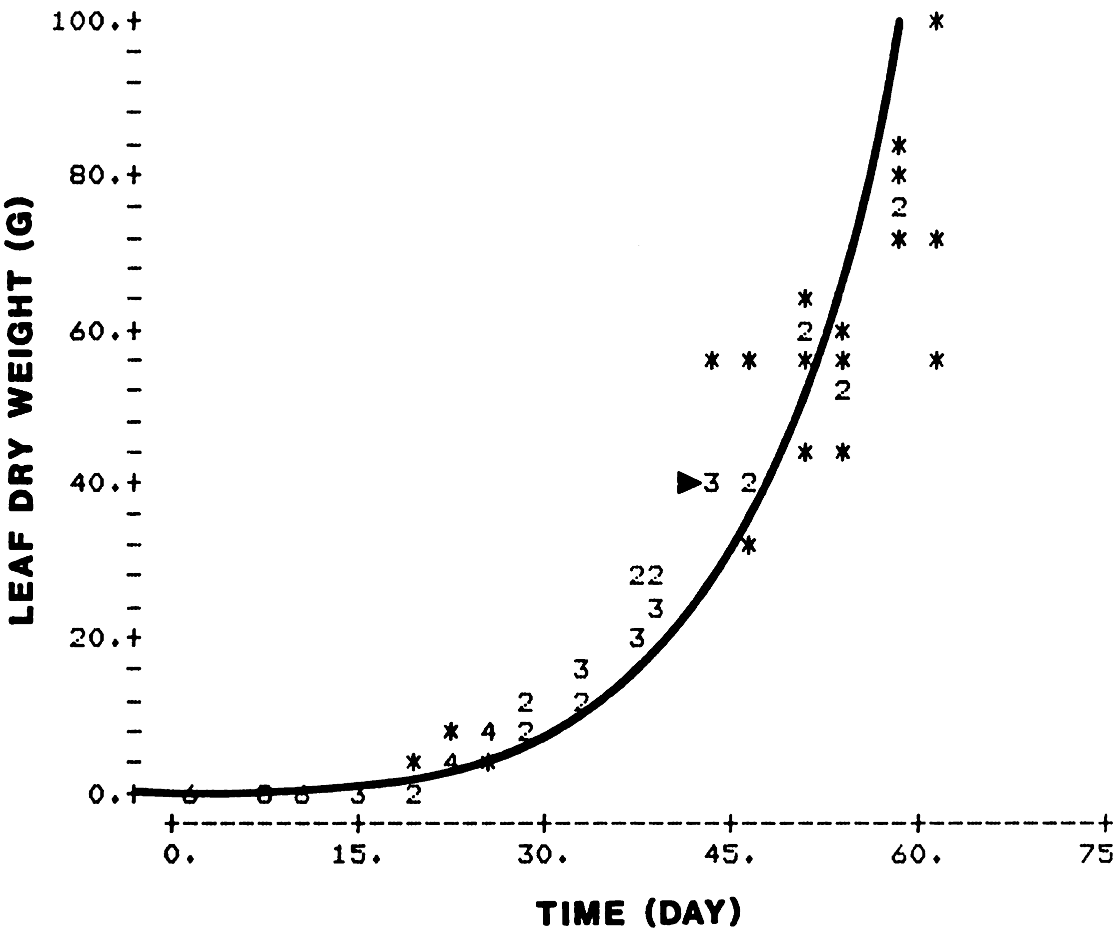
The tomato samples were more variable than were the bean samples. This resulted in lower R^2 values for all the tomato parts. No outstanding reason for the greater tomato variability was apparent.

The logarithmic bean leaf and stem growth functions reflected the short bean growing season. The longer growing tomato was adequately described by a quadratic equation. The fitted curves were incorporated into subroutines BNPART and TOMPART.

Functions relating leaf area to leaf dry weight were derived from the leaf area and leaf dry weight data. Similar functions were derived for predicting canopy ground area from leaf dry weight. These functions appear in subroutine CANOPY.

2. Fruit Fresh Weight : Dry Weight Ratios

Bean and tomato fruit fresh and dry weights, and their ratios, appear in Table 1. Due to the larger number of tomato data points, a function could be fitted to them rather than a simple ratio. The



* = one datum point

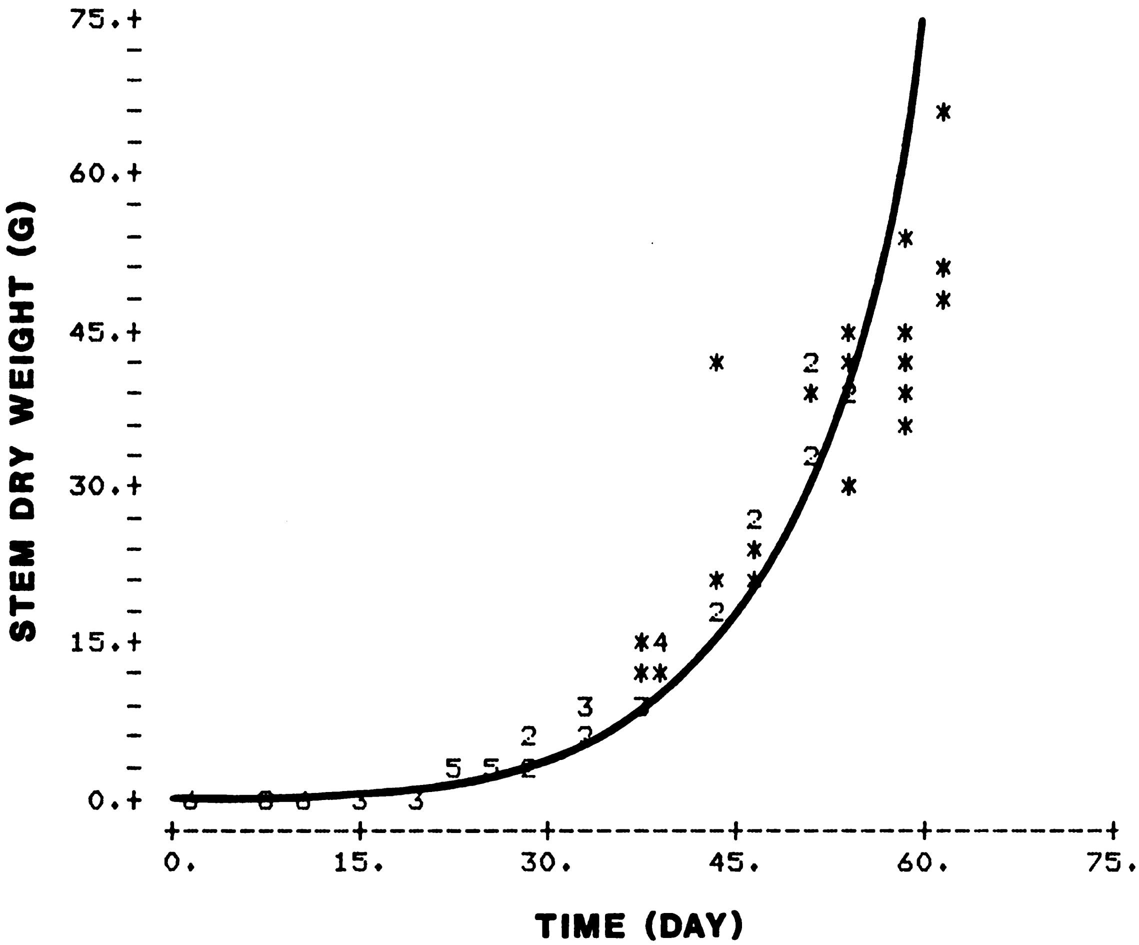
▶ = number of data at that position.

Fitted curve:

$$Y = 10^{(-.407 + .0425X)}$$

with: $R^2 = .95$, adjusted for 79 d.f.

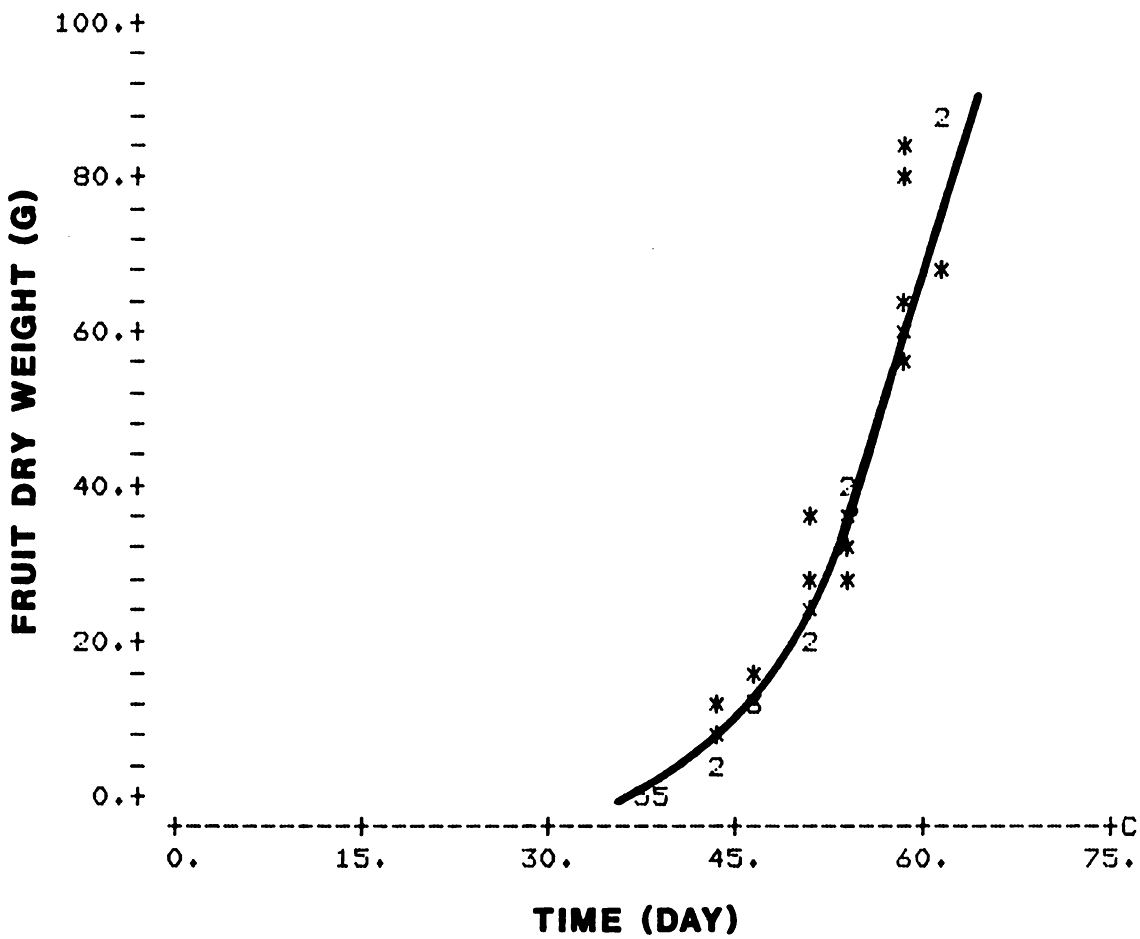
Figure 27: Bean leaf dry weights with fitted curve.



Fitted curve: $Y = 10^{(-.840 + .0466X)}$

with: $R^2 = .96$, adjusted for 79 d.f.

Figure 28: Bean stem dry weights with fitted curve.

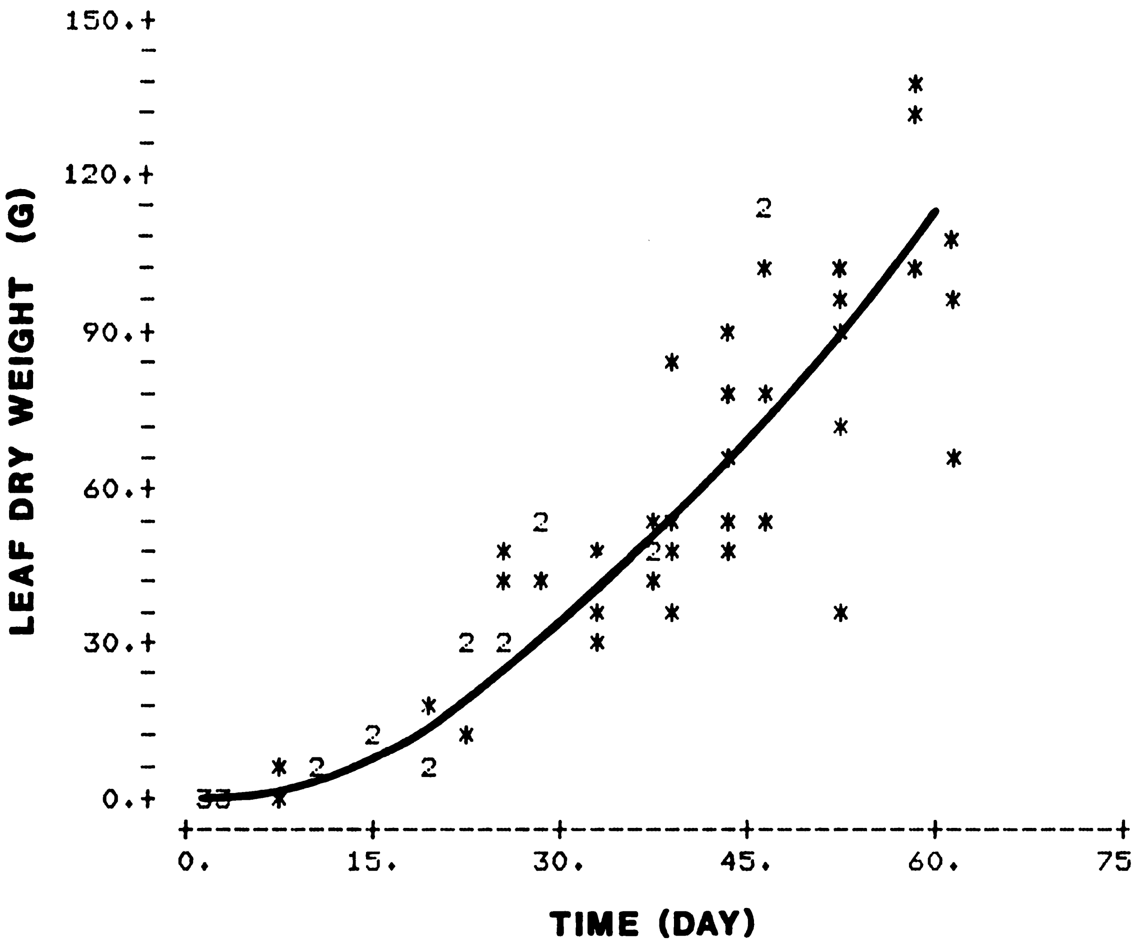


Fitted curve:

$$Y = 156.3 - 8.73X + .122X^2$$

with: $R^2 = .97$, adjusted for 34 d.f.

Figure 29: Bean fruit dry weights with fitted curve.

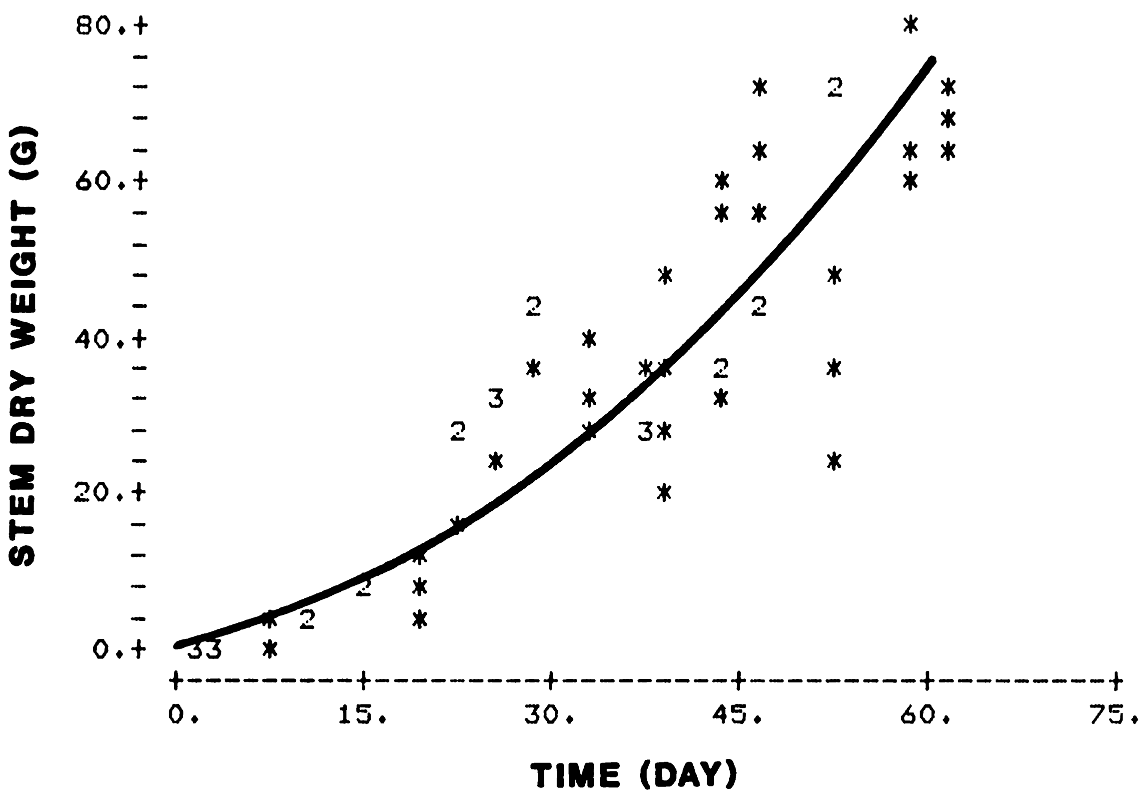


Fitted curve:

$$Y = .882 + .308X = .0269X^2$$

with: $R^2 = .87$, adjusted for 55 d.f.

Figure 30: Tomato leaf dry weights with fitted curve.

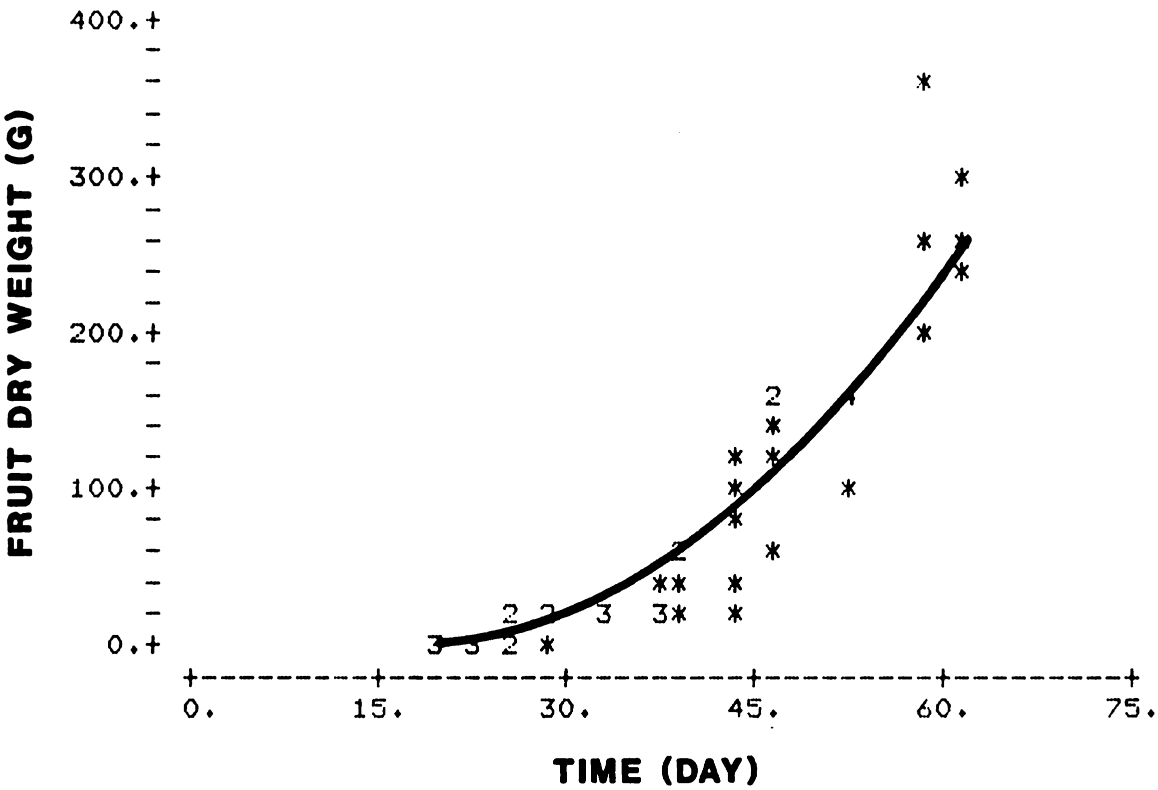


Fitted curve:

$$Y = 1.17 = .274X + .0161X^2$$

with: R^2 = .85, adjusted for 55 d.f.

Figure 31: Tomato stem dry weight with fitted curve.



Fitted curve:

$$Y = 47.3 - 5.10X + .138X^2$$

with: $R^2 = .89$, adjusted for 43 d.f.

Figure 32: Tomato fruit dry weight with fitted curve.

Table 1. Bean and Tomato Fruit Fresh Weight:Dry Weight Ratios

Bean	Sample	Fresh Weight (kg)	Dry Weight (g)	Ratio
	1	1.22	87.55	.0139
	2	1.79	123.75	.0145
	3	1.76	129.50	.0136
Tomato	**Fruit Color**	**Ave. Fruit Fresh Weight (kg)**	**Ave. Fruit Dry Weight (g)**	**Ratio**
	Mature Green	.1667	7.69	.0216
	1/2 Red	.2162	7.74	.0279
	Firm Ripe	.2753	11.42	.0241

functions used in the model appear in Materials and Methods on page 16.

3. Soil Water Content

The gravimetric soil water content remained quite high by July 16, 1980. A diminution was apparent (Figure 33), but the upper .3 m retained 10-12% water. The WATER subroutine is not functioning correctly in the present version of the model. It fails to increment soil moisture accurately. It appeared that soil moisture deficits had little impact on the validation experiment. This model deficiency probably did not significantly affect the simulated yields.

4. Preliminary Hexagon Trial

Field space limitations prevented replication of this experiment. No statistical analysis of the data was performed. However, the experiment provided valuable information regarding the plant spacings selected (Table 2).

Bean yield per plant more than doubled as bean-bean distance changed from .05 to .15 m. A slight response was observed with increased hexagon size and a constant bean-bean distance.

Tomato yield was less consistent. Yields in all the .8 m hexagons and .05 m bean rows were smaller than those from the other spacings, which were indistinguishable.

Visual observations confirmed that canopy density, and therefore, plant competition, varied noticeably across the plots. From these data and observations it was decided to retain the 9 spacing combinations used in the trial.

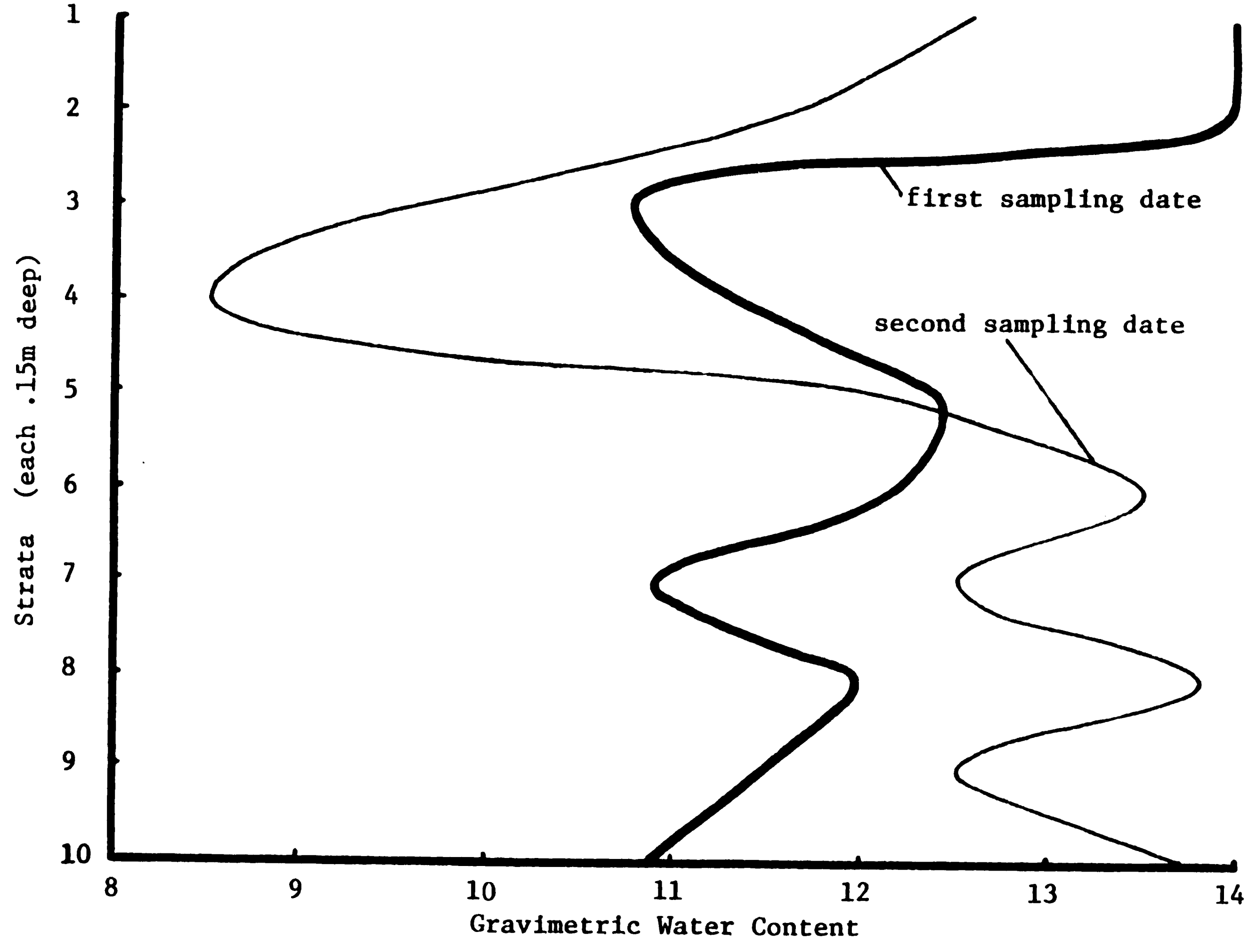


Figure 33. Gravimetric Soil Water Content

Table 2. Bean and Tomato Yield per Plant (kg)

Tomato distance (m)	Bean distance (m): .05	.10	.15	
.8	.047	.084	.114	.082
1.0	.047	.092	.125	.088
1.2	.054	.117	.159	.110
	.049	.098	.133	

Bean yield per plant (kg)

Tomato distance (m)	Bean distance (m): .05	.10	.15	
.8	1.09	2.77	1.81	1.89
1.0	2.63	2.95	3.63	3.07
1.2	2.00	3.36	3.49	2.95
	1.91	3.03	2.98	

Tomato yield per plant (kg)

B. SIMULATION RESULTS

Component and total populations varied widely across the 9 possible spacing combinations (Table 3). Total population per hectare at .8 m tomato-tomato and .05 m bean-bean distances was 4.5 times that at 1.2 m and .15 m respectively. The component and total population variation profoundly influenced yield per unit area.

1. Spacing Simulation

Component and total fruit yields appear in Tables 4-12. Simulation results from 9 planting distance combinations, and 4 bean starting dates, appear in Tables 4-7 (weather data from 1970) and Tables 9-12 (weather data from 1968). Results from a single series of 9 simulations with only the earliest bean starting date, and 1969 weather data, appear in Table 8. Results from 3 simulations with 5. m tomato-tomato distance and 2. m bean-bean distance using 1968-1970 weather data are in Table 13.

The following discussion centers primarily on Tables 4-7, with 1970 weather data. The same trends are apparent in the 1968 results (Tables 9-12).

a. Bean Fruit Yield.

When tomato-tomato distance was held constant, bean yield per plant doubled as bean planting distance increased from .05 m to .15 m. This ratio was constant over the 4 bean starting dates.

When bean-bean distance was held constant, bean yield per plant increased approximately 50% as tomato-tomato distance increased from .8 m to 1.2 m. Maximum bean

Table 3. Component and Total Populations at Each Planting Distance Combination

BEAN POPULATIONS

Per Hexagon

Bean distance (m)

Tomato distance (m)	.05	.10	.15
.8	55	28	18
1.0	69	35	23
1.5	83	42	28

Per Hectare

Bean distance (m)

Tomato distance (m)	.05	.10	.15
.8	500072	250036	166691
1.0	400058	200029	133353
1.5	333381	166691	111127

TOMATO POPULATIONS

Per Hectare

Bean distance (m)

Tomato distance (m)	.05	.10	.15
.8	18043	18043	18043
1.0	11547	11547	11547
1.5	8019	8019	8019

TOTAL POPULATIONS

Per Hectare

Bean distance (m)

Tomato distance (m)	.05	.10	.15
.8	518115	268079	184733
1.0	411605	211576	144900
1.5	341400	174710	119146

Table 4. Component and Total Yields Simulated from 1970 Weather Data with Bean Planting Date = 1, Bean Harvest Date = 52.

BEAN FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	.044	.066	.088
1.0	.055	.082	.109
1.2	.064	.097	.128

BEAN YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	2.213	1.655	1.471
1.0	2.196	1.649	1.456
1.2	2.127	1.612	1.419

TOMATO FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.878	2.001	2.064
1.0	1.968	2.084	2.156
1.2	2.069	2.188	2.283

TOMATO YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	3.388	3.610	3.724
1.0	2.273	2.407	2.490
1.2	1.659	1.755	1.831

COMBINED YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	5.601	5.265	5.194
1.0	4.469	4.056	3.746
1.2	3.786	3.366	3.250

Table 5. Component and Total Yields Simulated from 1970 Weather Data with BEANPLANT = 10, HARVEST = 62

BEAN FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	.043	.064	.085
1.0	.053	.080	.106
1.2	.062	.092	.125

BEAN YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.15	.15
.8	2.127	1.607	1.422
1.0	2.107	1.595	1.408
1.2	2.055	1.539	1.389

TOMATO FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.684	1.762	1.816
1.0	1.883	1.994	2.087
1.2	1.996	2.169	2.247

TOMATO YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	3.038	3.179	3.277
1.0	2.174	2.303	2.410
1.2	1.601	1.739	1.801

COMBINED YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	5.165	4.785	4.699
1.0	4.280	3.898	3.818
1.2	3.655	3.278	3.190

Table 6. Component and Total Yields Simulated from 1970 Weather Data with BEANPLANT = 20, HARVEST = 72

BEAN FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	.037	.056	.074
1.0	.046	.069	.092
1.2	.053	.080	.107

BEAN YIELD/UNIT AREA (kg m^{-2})

Toamto distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.858	1.392	1.234
1.0	1.841	1.383	1.222
1.2	1.783	1.333	1.191

TOMATO FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.518	1.577	1.669
1.0	1.829	1.908	1.980
1.2	2.126	2.256	2.315

TOMATO YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	2.738	2.846	3.011
1.0	2.112	2.204	2.286
1.2	1.705	1.809	1.856

COMBINED YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	4.596	4.237	4.246
1.0	3.952	3.587	3.508
1.2	3.488	3.142	3.047

Table 7. Component and Total Yields Simulated from 1970 Weather Data with BEANPLANT = 30, HARVEST = 82

BEAN FRUIT WEIGHT (kg)

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	.028	.042	.055
1.0	.034	.052	.069
1.2	.040	.060	.080

BEAN YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	1.391	1.045	.922
1.0	1.374	1.035	.916
1.2	1.333	1.005	.885

TOMATO FRUIT WEIGHT (kg)

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	1.460	1.863	2.007
1.0	1.706	1.974	2.171
1.2	2.115	2.228	2.365

TOMATO YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	2.635	3.361	3.621
1.0	1.970	2.279	2.507
1.2	1.696	1.787	1.896

COMBINED YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	4.205	4.406	4.543
1.0	3.345	3.314	3.423
1.2	3.030	2.791	2.781

Table 8. Component and Total Yields Simulated from 1969 Weather Data with BEANPLANT = 1, HARVEST = 52

BEAN FRUIT WEIGHT (kg)

Tomato distance (2)	Bean distance (m) .05	.10	.15
.8	.042	.062	.084
1.0	.052	.078	.104
1.2	.061	.091	.121

BEAN YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	2.093	1.562	1.395
1.0	2.075	1.552	1.381
1.2	2.021	1.520	1.342

TOMATO FRUIT WEIGHT (kg)

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	2.091	2.228	2.303
1.0	2.177	2.305	2.393
1.2	2.270	2.404	2.512

TOMATO YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	3.773	4.021	4.154
1.0	2.514	2.661	2.763
1.2	1.820	1.928	2.014

COMBINED YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	5.866	5.583	5.549
1.0	4.589	4.213	4.145
1.2	3.841	3.448	3.356

Table 9. Component and Total Yields Simulated from 1968 Weather Data with BEANPLANT = 1, HARVEST = 52

BEAN FRUIT WEIGHT (kg)

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	.032	.047	.063
1.0	.039	.058	.079
1.2	.046	.069	.092

BEAN YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	1.585	1.187	1.046
1.0	1.560	1.170	1.053
1.2	1.526	1.146	1.018

TOMATO FRUIT WEIGHT (kg)

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	2.227	2.381	2.469
1.0	2.327	2.480	2.573
1.2	2.444	2.587	2.696

TOMATO YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	4.017	4.296	4.455
1.0	2.687	2.864	2.971
1.2	1.960	2.074	2.162

COMBINED YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	5.603	5.483	5.502
1.0	4.247	4.034	4.024
1.2	3.486	3.221	3.180

Table 10. Component and Total Yields Simulated from 1968 Weather Data with BEANPLANT = 10, HARVEST = 62

BEAN FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	.039	.059	.079
1.0	.049	.073	.098
1.2	.057	.086	.114

BEAN YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.955	1.468	1.310
1.0	1.942	1.460	1.302
1.2	1.892	1.427	1.270

TOMATO FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.144	1.199	1.216
1.0	1.284	1.362	1.402
1.2	1.369	1.481	1.554

TOMATO YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	2.064	2.164	2.194
1.0	1.483	1.573	1.619
1.2	1.098	1.188	1.246

COMBINED YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	4.019	3.632	3.504
1.0	3.424	3.033	2.921
1.2	2.990	2.615	2.516

Table 11. Component and Total Yields Simulated from 1968 Weather Data with BEANPLANT = 20, HARVEST = 72

BEAN FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	.023	.034	.045
1.0	.028	.042	.057
1.2	.033	.050	.066

BEAN YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.142	.855	.757
1.0	1.136	.849	.755
1.2	1.105	.828	.733

TOMATO FRUIT WEIGHT (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.084	1.126	1.217
1.0	1.313	1.389	1.422
1.2	1.521	1.627	1.681

TOMATO YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.956	2.031	2.195
1.0	1.516	1.604	1.642
1.2	1.219	1.304	1.348

COMBINED YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	3.098	2.886	2.952
1.0	2.652	2.452	2.396
1.2	2.324	2.132	2.081

Table 12. Component and Total Yields Simulated from 1968 Weather Data with BEANPLANT = 30, HARVEST = 82

BEAN FRUIT WEIGHT (kg)

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	.015	.022	.030
1.0	.018	.028	.037
1.2	.021	.032	.043

BEAN YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	.743	.553	.492
1.0	.733	.550	.488
1.2	.712	.537	.475

TOMATO FRUIT WEIGHT (kg)

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	1.276	1.611	1.721
1.0	1.440	1.806	1.929
1.2	1.680	1.853	2.074

TOMATO YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	2.303	2.908	3.106
1.0	1.663	2.085	2.228
1.2	1.307	1.486	1.663

COMBINED YIELD/UNIT AREA (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	3.046	3.461	3.598
1.0	2.396	2.635	2.716
1.2	2.059	2.023	2.138

Table 13. Bean and Tomato Fruit Yields over 3 Different Years' Weather Data. Planting Distances Were 5 m Tomato-Tomato and 2 m Bean-Bean

Year	Bean Yield Per Plant (kg)	Tomato Yield Per Plant (kg)
1968	.578	2.803
1969	.675	2.984
1970	.723	3.742

yield per plant was at 1.2 m and .15 m tomato and bean spacings.

Bean yield per hexagon is confounded with the rapidly increasing bean population as hexagon width changes from .8 m to 1.2 m. Yields per hexagon are not reported here. Rather, yields per m^2 are reported because this relationship simultaneously accounts for changes in both population and area. Yield per hexagon deals only with population changes.

Maximum bean yield per m^2 occurred at .8 m and .05 m tomato and bean planting distances. This was exactly opposite to the individual plant optimal spacing. Individual plant yield maxima peaked where intra- and interspecific competition was at a minimum. Yield per unit area peaked where the competition was at a maximum.

b. Tomato Fruit Yield.

Maximum individual plant yield occurred with the most distant plant spacings. The relative yield increase when moving from .8 m and .15 m to 1.2 m and .15 m tomato and bean spacings was less than the relative bean yield increase over the same changes in planting distance. Maximum tomato yield per m^2 was at .8 m and .15 m tomato and bean distances. The bean canopy was not as tall with the .15 m spacing as with the .05 m spacing. Diminished shading from the .15 m spacing canopy allowed greater yield.

2. Model Response to Weather Changes

The model responded to differences in weather data. Yields generated using weather data from 1969 and 1968 appear in Tables 8 and 9-12, respectively. A comparison using the earliest bean commencement date is obtained by comparing Tables 4, 5 and 9.

The two species responded differently to the weather changes. Bean yields in descending order were from 1970, 1969 to 1968. Tomato yields in descending order were from 1968, 1969 to 1970, which was the opposite direction to the bean. The tomato pattern was not the same when the plants were simulated as free-standing individuals (Table 13). In this case, the tomato yields paralleled the bean yields in descending order over 1970, 1969 to 1968. This reversal is largely due to the dominance of the bean canopy in the model caused by the bean shading effects. When the bean grew relatively better, tomato growth was diminished.

C. VALIDATION RESULTS AND SIMULATION COMPARISON

1. Spacing Experiment.

Bean yields per plant differed significantly (1% level) as a result of changes in either bean-bean or tomato-tomato distances. Bean yield per unit area differed significantly (1% level) only in response to change in bean-bean spacing (Table 14). The mean separations of yield per unit area revealed no difference due to changes in tomato-tomato distance. However, there was a trend toward increased yield with .8 m hexagons (Table 15).

Table 14. Analysis of Variance (ANOVA) of the Spacing Experiment Bean Yields

ANOVA OF BEAN YIELD (WEIGHT PER PLANT)

Source of variation	df	Mean square	F
Replication	2	.00015	.579
Tomato spacing	2	.00717	27.145**
Error a	4	.00026	
Bean spacing	2	.0244	81.078**
Tomato spacing x Bean spacing	4	.00008	.262
Error b	12	.00030	

ANOVA OF BEAN YIELD (WEIGHT PER UNIT AREA)

Source of variation	df	Mean square	F
Replication	2	.062	.540
Tomato spacing	2	.261	2.284
Error a	4	.114	
Bean spacing	2	.709	17.873**
Tomato spacing x Bean spacing	4	.079	1.991
Error b	12	.040	

Table 15. Spacing Experiment Bean Fruit Yields with Averages Separated by the Duncan's Multiple Range Test

WEIGHT PER PLANT (kg)

Tomato distance (cm)	Bean distance (cm): 5	10	15	
80	.042	.074	.099	.072c
100	.057	.091	.12	.089b
120	.069	.11	.13	.103a
	.056c	.092b	.116a	

WEIGHT PER UNIT AREA (kg m^{-2})

Tomato distance (cm)	Bean distance (cm): 5	10	15	
80	1.68	1.64	1.51	1.61a
100	1.86	1.52	1.34	1.57a
120	1.58	1.41	1.29	1.43a
	1.71a	1.52b	1.38c	

Tomato yields per plant differed significantly (1% level) as a result of changes in either bean-bean or tomato-tomato distances. Tomato yields per unit area differed significantly (5% level) only in response to changes in bean-bean spacing (Table 16). The mean separations confirmed the lack of difference in yield per unit area over different tomato-tomato distances (Table 17).

Comparisons of the simulation and validation yields appear in Tables 18-20.

Simulated bean yields per plant from 1970 weather data closely paralleled validation yields at each spacing combination. A Chi^2 test to assess the goodness of fit of the two data sets was significant at the 1% level.

The goodness of fit of simulation and validation bean yields per unit area was not significant. This was contributed to by errors in bean populations in the field. Cold, wet weather during bean germination, followed by warm, dry weather and soil surface crusting, led to uneven germination across the plots. Some plots did not reach their specified population levels. The validation did support the prediction of maximum bean yield at the .05 m bean-bean distance (Table 15).

Simulation tomato yields per plant followed the same direction as the validation, but were not significant (Table 19). Tomato yields per plant doubled from minimum to maximum levels in the field, but increased only 18% in the simulation. However, the range of simulated yields was similar to the validation results.

Simulation and validation yields per unit area for tomato showed similar trends, but again were not significant (Table 19). As bean-bean distance increased, tomato yields also increased. However,

Table 16. Analysis of Variance (ANOVA) of the Spacing Experiment Tomato Yields

ANOVA OF TOMATO YIELD (WEIGHT PER PLANT)

Source of Variation	df	Mean square	F
Replication	2	1.030	1.296
Tomato spacing	2	21.797	27.425**
Error a	4	.795	
Bean spacing	2	2.651	8.163**
Tomato x Bean spacing	4	.410	1.262
Error b	12	.325	

ANOVA OF TOMATO YIELD (WEIGHT PER UNIT AREA)

Source of Variation	df	Mean square	F
Replication	2	.823	.828
Tomato spacing	2	2.482	2.497
Error a	4	.994	
Bean spacing	2	3.407	5.533*
Tomato x Bean spacing	4	.348	.566
Error b	12	.616	

Table 17. Spacing Experiment Tomato Fruit Yields with Averages Separated by the Duncan's Multiple Range Test

WEIGHT PER PLANT (kg)

		Bean distance (cm)			
		5	10	15	
Tomato distance (cm)	80	1.55	1.90	1.82	1.76b
	100	1.79	2.27	2.62	2.23b
	120	3.05	3.89	3.53	3.49a
		2.12b	2.69a	2.66a	

WEIGHT PER UNIT AREA (kg m^{-2})

		Bean distance (cm)			
		5	10	15	
Tomato distance (cm)	80	2.80	3.43	3.28	3.17a
	100	2.07	2.62	3.02	2.57a
	120	2.45	3.12	2.83	2.80a
		2.44b	3.06a	3.04a	

Table 18. Bean Fruit Yields per Plant and per Unit Area from Simulations and the 1980 Spacing Validation Experiment

SIMULATION (1970 weather)

Fruit weight/plant (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	.044	.066	.088
1.0	.055	.082	.109
1.2	.064	.097	.128

Fruit weight/unit area (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	2.213	1.655	1.471
1.0	2.196	1.649	1.456
1.2	2.127	1.612	1.419

VALIDATION (1980)

Fruit weight/plant (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	.042	.074	.099
1.0	.057	.091	.12
1.2	.069	.11	.13

Fruit weight/unit area (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.68	1.64	1.51
1.0	1.86	1.52	1.34
1.2	1.58	1.41	1.29

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Table 19. Tomato Fruit Yields per Plant and per Unit Area from Simulations and the 1980 Spacing Validation Experiment

SIMULATION (1970 weather)

Fruit weight/plant (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.878	2.001	2.064
1.0	1.968	2.084	2.156
1.2	2.069	2.188	2.283

Fruit weight/unit area (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	3.388	3.610	3.724
1.0	2.273	2.407	2.490
1.2	1.659	1.755	1.831

VALIDATION (1980)

Fruit weight/plant (kg)

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	1.55	1.90	1.82
1.0	1.79	2.27	2.62
1.2	3.05	3.89	3.53

Fruit weight/unit area (kg m^{-2})

Tomato distance (m) \ Bean distance (m)	.05	.10	.15
.8	2.80	3.43	3.28
1.0	2.07	2.62	3.02
1.2	2.45	3.12	2.83

variability in the field reduced the clarity of this comparison as it did with the bean. In this case only one plant was involved in each hexagon, so the specified population was always met. The variability was, therefore, entirely in plant growth.

Total yields of both species per unit area appear in Table 20. The simulation predicted a maximum total yield at .8 m and .05 m tomato and bean distances. This was due to the overriding influence of the bean yields. The validation results were too random to be useful. However, given the results for each species previously presented, it seems reasonable to expect that maximum yields in this system would come from .8 m and .05 m tomato and bean distances, out of the spacing combinations tested.

2. Planting Date Experiment

Bean yields per plant and per unit area differed significantly (1% level) as a result of changes in either bean-bean distance or planting date (Tables 21, 22). Tomato-tomato distance was significant in neither case, as in the spacing experiment (Table 14). The early bean planting produced significantly higher yields than did the later planting (Tables 23, 24).

Tomato yields per plant and per unit area differed significantly (5% level) as a result of changes in planting date. Yields per unit area also differed significantly (1% level) as a result of changes in tomato-tomato distance. Tomato x bean distances and planting date x bean distance interactions were both significant at the 1% level in the yields per plant and per unit area (Table 25).

Table 20. Total Yields per Unit Area from Simulations and the 1980 Spacing Validation Experiment

SIMULATION (1970 Weather)

Fruit Weight/Unit Area (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	5.165	4.785	4.699
1.0	4.280	3.898	3.818
1.2	3.655	3.278	3.190

VALIDATION (1980)

Fruit Weight/Unit Area (kg m^{-2})

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	4.48	5.07	4.79
1.0	3.93	4.14	4.36
1.2	4.03	4.53	4.12

Table 21. Analysis of Variance (ANOVA) of the Planting Date Experiment Bean Yields per Plant.

ANOVA OF BEAN YIELD (WEIGHT PER PLANT)

Source of Variation	df	Mean Square	F
Replication	2	.00056	.348
Tomato	2	.00349	2.188
Error a	4	.00159	
Bean	2	.01807	38.184**
Tomato x Bean	4	.00049	1.033
Error b	12	.00047	
Planting	1	.02160	35.453**
Planting x Tomato	2	.00060	.985
Planting x Bean	2	.00136	2.225
Planting x Tomato x Bean	4	.00021	.337
Error c	18	.00061	

Table 22. Analysis of Variance (ANOVA) of the Planting Date Experiment Bean Yields per Unit Area

ANOVA OF BEAN YIELD (WEIGHT PER UNIT AREA)

Source of Variation	df	Mean Square	F
Replication	2	.028	.101
Tomato	2	.042	.151
Error a	4	.278	
Bean	2	1.361	13.858**
Tomato x Bean	4	.111	1.131
Error b	12	.098	
Planting	1	1.245	13.299**
Planting x Tomato	2	.206	2.198
Planting x Bean	2	.158	1.691
Planting x Tomato x Bean	4	.106	1.135
Error c	18	.094	

Table 23. Planting Date Experiment Bean Fruit Yields per Plant with Averages Separated by the Duncan's Multiple Range Test.

WEIGHT PER PLANT (kg)

Tomato distance (m)	Bean distance (m) .05	.10	.15		Date
.8	.077	.13	.13		1
1.0	.070	.12	.16		.119a
1.2	.087	.12	.18		

Tomato distance (m)	Bean distance (m) .05	.10	.15		Date
.8	.043	.053	.080	.086a	2
1.0	.063	.073	.11	.099a	.0796
1.2	.067	.093	.13	.113a	
	.068c	.098b	.132a		

Table 24. Planting Date Experiment Bean Fruit Yields per Unit Area with Averages Separated by the Duncan's Multiple Range Test.

WEIGHT PER UNIT AREA (kg m^{-2})

Bean distance (m)

Tomato distance (m)	.05	.10	.15	Date
.8	2.47	2.09	1.28	1
1.0	2.04	1.70	1.65	1.80a
1.2	1.86	1.57	1.51	

Bean distance (m)

Tomato distance (m)	.05	.10	.15		Date
.8	1.73	1.22	1.30	1.68a	2
1.0	1.79	1.33	1.48	1.67a	1.49b
1.2	1.85	1.39	1.36	1.59a	
	1.96a	1.55b	1.43b		

Table 25. Analysis of Variance (ANOVA) of the Planting Date Experiment Tomato Yields.

Bean = bean-bean distance

Plant = bean planting date

Tomato = tomato-tomato distance

ANOVA OF TOMATO YIELD (WEIGHT PER PLANT)

Source of Variation	df	Mean square	F
Replication	2	1.872	.899
Tomato	2	1.982	.951
Error a	4	2.083	
Bean	2	.326	.961
Tomato x Bean	4	3.550	10.452**
Error b	12	.340	
Planting	2	3.119	3.508*
Planting x Tomato	4	.433	.487
Planting x Bean	4	3.741	4.208**
Planting x Tomato x Bean	8	.406	.457
Error c	36		

ANOVA OF TOMATO YIELD (WEIGHT PER UNIT AREA)

Source of Variation	df	Mean square	F
Replication	2	2.576	1.211
Tomato	2	40.960	19.256**
Error a	4	2.127	
Bean	2	.602	1.408
Tomato x Bean	4	3.370	7.888**
Error b	12	.427	
Planting	2	6.188	4.299*
Planting x Tomato	4	2.050	1.424
Planting x Bean	4	6.175	4.290**
Planting x Tomato x Bean	8	.983	.683
Error c	36		

Table 26. Tomato Fruit Yields per Plant in the Planting Date Experiment, with Averages Separated by the Duncan's Multiple Range Test*

Plant Date 1

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	1.54aAY	1.31aAY	1.76aAy
1.0	1.70aAY	1.43aAX	1.18aAX
1.2	1.70aAXY	1.01aAY	2.31aAX
Mean[1]	1.65	1.25	1.75

Plant Date 2

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	1.56aAY	2.35aAX	2.78aAX
1.0	1.59aAY	2.03aAX	1.09aBX
1.2	.94aAY	2.44aAX	3.15aAX
Mean[1]	1.36	2.27	2.34

Plant Date 3

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	3.45aAX	2.61aAX	1.92aAXY
1.0	3.44aAX	1.51aAX	.59bBX
1.5	2.21aAX	1.49aAXY	2.75aAX
Mean[1]	3.03	1.87	1.75

MEAN YIELD AT CONSTANT TOMATO AND BEAN DISTANCE ACROSS PLANTING DATE

Tomato distance (m)	Bean distance (m) .05	.10	.15
.8	2.18	2.09	2.15
1.0	2.24	1.66	.95
1.2	1.62	1.65	2.74

*A, B, C = bean distance
a, b, c = tomato distance
X, Y = planting date

[1]Mean yield at constant bean spacing within planting date.

Tabl

Table 27. Tomato Fruit Yields per Unit Area in the Planting Date Experiment, with Averages Separated by the Duncan's Multiple Range Test*

Plant date 1

Tomato distance(m)	Bean distance(m) .05	.10	.15
.8	2.78aAY	2.37aAY	3.17aAY
1.0	1.97aAY	1.65aAX	1.36aAX
1.2	1.47aAXY	.81aAX	1.86aAX
Mean[1]	2.07	1.61	2.13

Plant date 2

Tomato distance(m)	Bean distance(m) .05	.10	.15
.8	2.81bAY	4.25abAX	5.01aAX
1.0	1.83aABY	2.35aBX	1.25aBX
1.2	.75aBY	1.96aBX	2.53aBX
Mean[1]	1.80	2.85	2.93

Plant date 3

Tomato distance(m)	Bean distance(m) .05	.10	.15
.8	6.19aAX	4.70abAX	3.47bAY
1.0	5.82aAX	1.74bBX	.68bBX
1.2	2.21aBX	1.20aBX	2.21aABX
Mean[1]	4.74	2.55	2.12

MEAN YIELD AT CONSTANT TOMATO AND BEAN DISTANCE ACROSS PLANTING DATE

Tomato distance(m)	Bean distance(m) .05	.10	.15
.8	3.93	3.77	3.88
1.0	3.21	1.91	1.10
1.2	1.48	1.32	2.20

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*A, B, C = bean distance
a, b, c = tomato distance
X, Y = planting date

[1]Mean yield at constant bean spacing within planting date.

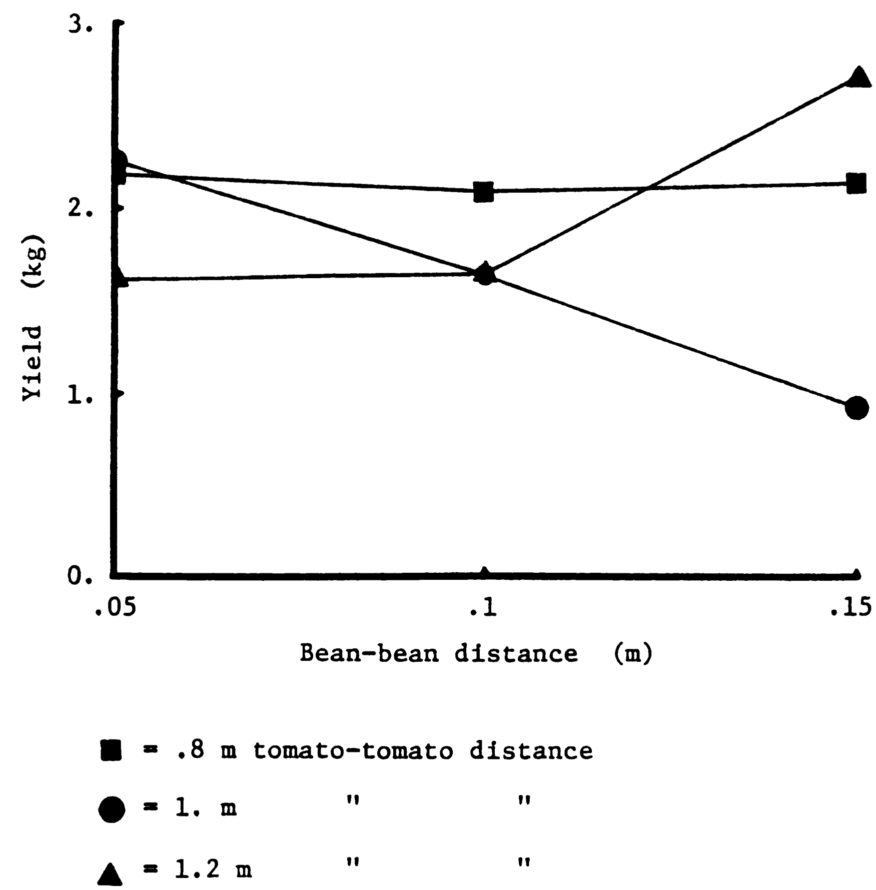

Figure 34. Tomato yields per plant in the planting date experiment. Data are means of yields at constant tomato and bean distances across planting dates. Refer Table 26.

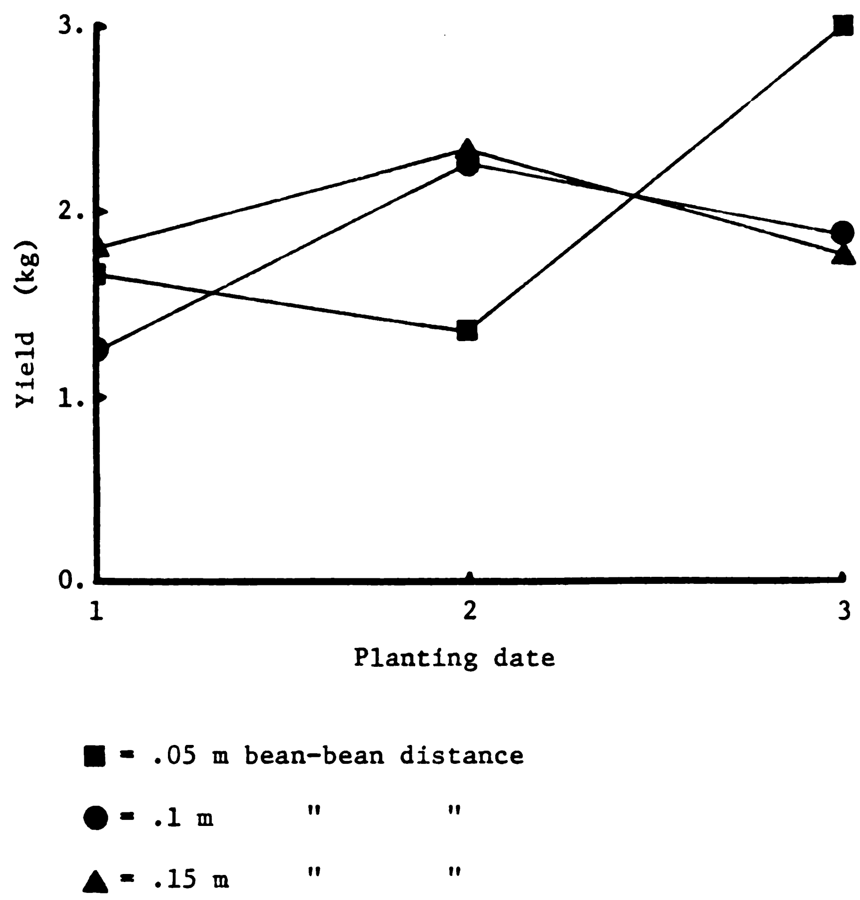

Figure 35. Tomato yields per plant in the planting date experiment. Data are means of yields at constant bean spacing within planting date. Refer Table 26.

Fig.

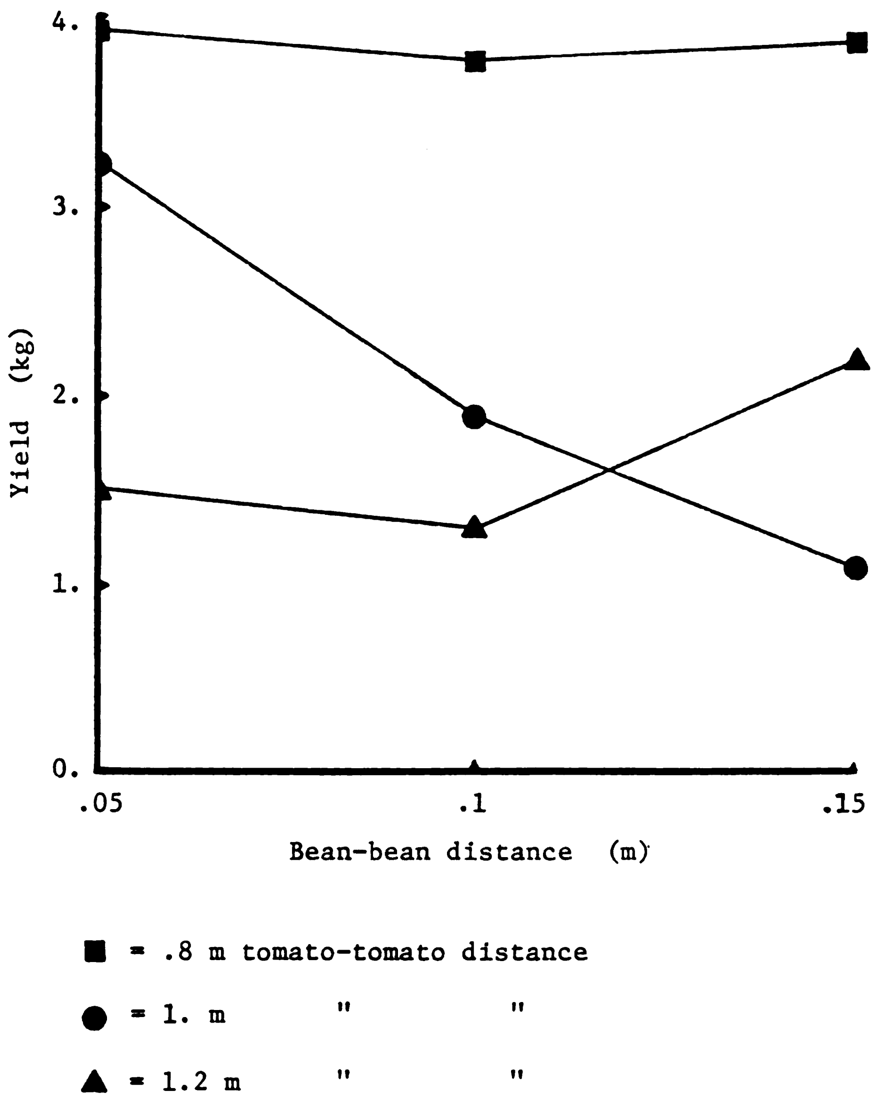

Figure 36. Tomato yields per unit area in the planting date experiment. Data are means of yields at constant tomato and bean distances across planting dates. Refer Table 27.

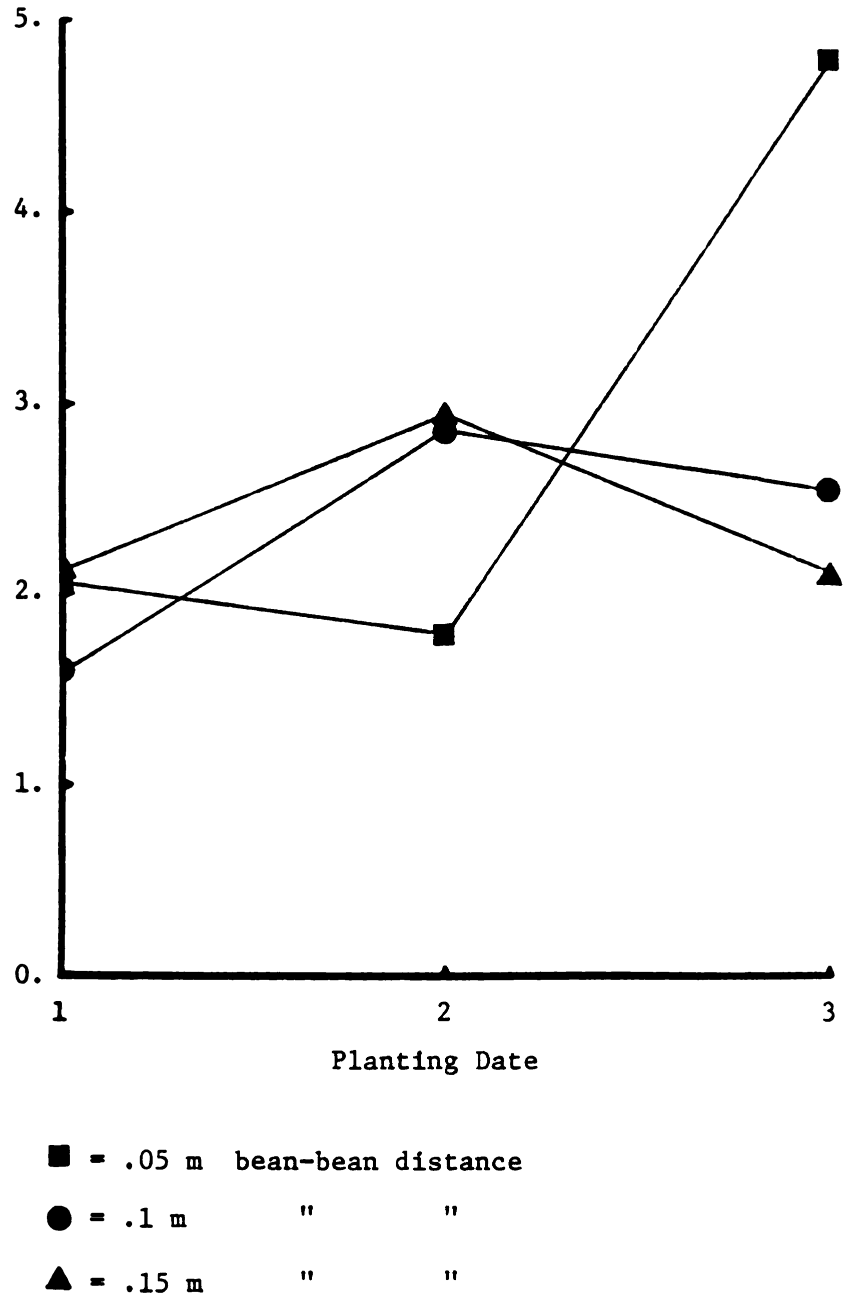

Figure 37. Tomato yields per unit area in the planting date experiment. Data are means of yields at constant bean spacing within planting date. Refer Table 27.

Tomato yields per plant and per unit area are shown in Tables 26 and 27. Means across planting dates with tomato and bean distances held constant, and across tomato distance with planting date and bean distance held constant, are also shown. These means assist interpretation of the interactions, and are presented graphically in Figures 34-37.

The tomato x bean planting distances interaction from the tomato yield per plant ANOVA is depicted graphically in Figure 34. Yields were constant with .8 m tomato-tomato distance as bean-bean distance increased. However, with 1. and 1.2 m tomato-tomato distance the yields decreased and increased respectively as bean-bean distance increased. Similar results occurred in yield per unit area (Figure 36).

The bean planting date x bean-bean distance interaction from the tomato yield per unit area is depicted graphically in Figure 35. Yield per plant increased with the third planting date when bean-bean distance was held constant at .05 m (Figure 35). No such increase occurred with the two larger bean-bean distances. Similar trends occurred with this interaction in tomato yield per unit area (Figure 37).

The reasons for these interactions are not clear. No tomato x bean distance interaction occurred in the spacing experiment. Its presence in the planting date experiment may have been an aberration unique to that season. Further field experiments would be required to establish its importance.

A partial explanation of the tomato yield increase in the .05 m bean-bean distance hexagons in planting date 3 is possible. The beans were killed by frost damage in this final planting. Also, the intense bean competition did not occur until late in the season, and was dim

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diminished by tomato shading of the bean canopy. The reduction in bean competition may have had a relatively greater effect with the .05 m bean-bean than with the lower competition from the wider bean spacings.

A comparison of simulation and validation bean yields across 2 planting dates appears in Table 28. Yield reductions in weight per plant as planting date was retarded were 37% and 33% in the simulation and validation yields respectively. The yield reductions in weight per unit area as planting date was retarded were 37% and 17% in simulation and validation yields respectively. Comparisons of simulation and validation yields for tomato are not made here because of the interactions.

These results reconfirm that the canopy shading section of the model has captured a significant part of the real system. Without that section, neither the changes in planting distances nor bean planting dates would have caused the simulation yield changes reported.

Table 28. Comparison of Average Yield for All Plant Spacing Combinations at each of 2 Bean Planting Dates. Simulated Yields Were for 1970 Weather Data, and BEANPLANT = 1 or 30

Planting Date	Average Yield for All Planting Combinations			
	Weight/Plant (kg)		Weight/Unit Area (kg m^{-2})	
	Simulation	Validation	Simulation	Validation
1	.081	.119	1.76	1.80
30	.051	.080	1.10	1.49

SUMMARY AND CONCLUSIONS

The optimum plant spacings, of those combinations tested, for maximizing bean and total yields were .05 m bean-bean and .8 m tomato-tomato distances. Maximum tomato yields were at .15 m bean-bean and .8 m tomato-tomato distances. These maximum yields occurred with the earliest bean planting date.

It has not been shown whether closer spacings would produce greater yields. However, it is expected that the above spacings are close to the ideal for maximum yields.

The model performs well in its present form. Simulation and validation bean yields were significant at the 1% level. Although all other results were not significant, the simulation results were of the same order of magnitude and moved in similar directions to the validation yields.

Further work with the model is required for increased accuracy. The soil water subroutine is not functioning correctly and needs reworking. No attempt has been made to model root competition for water and nutrients. This area is vital to overall competition.

Tomato shading of the beans should be incorporated into the photosynthesis subroutine. This is especially important for later bean plantings which are shaded by a relatively large tomato plant.

Presently the model uses the bean plant nearest to the tomato. A more representative bean plant would be the plant located equidistant between the nearest and furthest bean plants.

Potential tests and uses of the model include modification of some existing constants, rates, spacings, etc. Photosynthetic rates could be reduced by a known amount, and yields observed to determine if the yield reduction was equivalent. Different canopy shapes and types could be incorporated, such as caged tomatoes or pole beans. The planting design could be converted to rows, or even to a monoculture.

The program has numerous comments throughout to enable another person to quickly comprehend it. It is hoped that others will take this current version and improve and modify it for new purposes.

APPENDICES

APPENDIX A

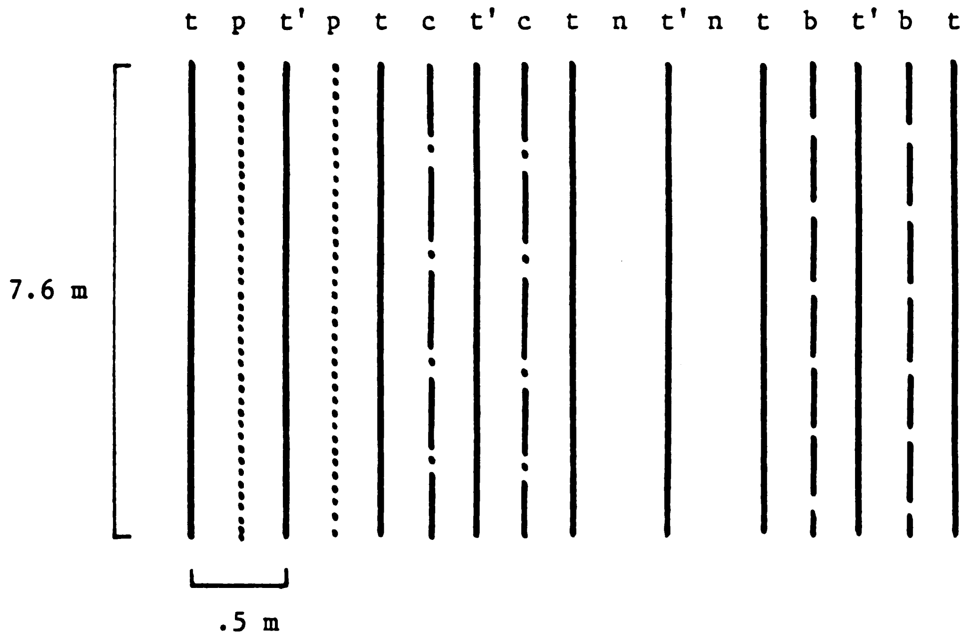


Figure 38. Plot design for one replicate of preliminary intercropping experiment.

Where:

b = bean row

c = cabbage row

n = no intercrop between tomato rows

p = pea row

t = tomato guard row

t' = tomato harvested row

Table 29. Tomato Yields for 1978 and 1979 from the Preliminary Intercropping Experiment

TOMATO YIELD

Intercropped species	Year	Yield (tons/acre)	Percent of control
control	1978	33.2	
	1979	24.8	
cabbage	1978	18.6	56
	1979	13.4	54
pea	1978	20.7	62
	1979	19.3	78
bean	1978	27.2	82
	1979	17.2	69

Table 30. Cabbage, Pea and Bean Yields for 1978 and 1979 from the Preliminary Intercropping Experiment

CABBAGE YIELDS

Situation	Yield (tons/acre) 1978	1979	Percent of control 1978	1979
intercropped	11.1	9.5	116	133
control	9.6	7.1		

PEA YIELDS

Situation	Yield (tons/acre) 1978	1979	Percent of control 1978	1979
intercropped	2.6	2.3	124	164
control	2.1	1.4		

BEAN YIELDS

Situation	Yield (tons/acre) 1978	1979	Percent of control 1978	1979
intercropped	3.7	4.4	73	85
control	5.1	5.2		

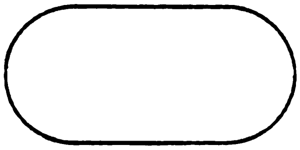
APPENDIX B

APPENDIX B

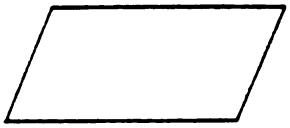
Glossary of modeling terms.

state variables	- elements describing the components of the system; levels or amounts of material. Examples are leaf dry weight, photosynthate produced in one hour, and leaf area index.
rate variables	- rates of transfer of material between state variables per unit time.
driving variables	- forces external to but acting upon the system. Examples are solar radiation, temperature, rainfall and relative humidity.
output variables	- states or rates produced by the model and which are the objectives of the system.
system boundary	- the boundary between the system and its environment.
exogenous	- outside the system boundary.

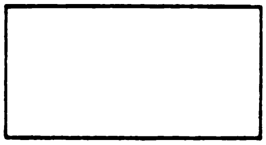
Flowcharting Symbols (36,72)



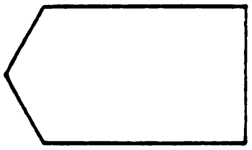
Beginning or end of
an algorithm



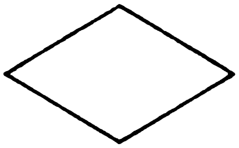
Any input or output
operation



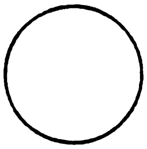
Arithmetic calculation
or state variable



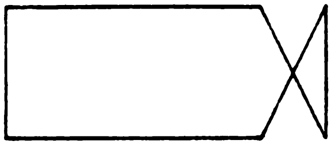
Beginning of series
of operations to be
performed repetitively;
a DO loop



Comparison or
decision making



Jump (used to direct
to another flowchart
segment)



Rate variable

APPENDIX C

Climatic data for 1968, 1969, 1970 and 1980 compiled from Local Climatological Data, National Climatic Center, and from data provided by the Agricultural Weather Service, Michigan State University.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Annual	May-Sept.
Average Temperature (F) 1968	20.1	21.2	36.7	48.9	53.2	66.5	70.2	69.5	62.7	51.3	37.5	25.5	46.9	64.4
1969	21.8	25.4	30.4	47.2	56.5	61.9	71.1	72.8	64.2	50.0	36.2	25.8	47.0	65.3
1970	16.4	23.6	29.1	46.5	58.6	65.5	70.2	68.2	61.5	51.8	39.1	25.8	46.3	64.8
1980	22.2	19.6	29.9	45.0	58.5	63.5	72.5	71.8	61.8	45.2	36.7	23.7	45.9	65.6
Precipitation (In) 1968	1.46	1.56	1.49	2.96	4.16	7.94	3.03	2.98	2.73	1.56	3.26	2.62	35.75	20.8
1969	1.91	0.22	1.06	4.02	4.47	4.03	4.89	0.17	1.67	2.74	2.32	0.53	28.03	15.2
1970	0.91	0.66	2.20	3.13	2.89	3.02	3.37	2.36	4.61	3.77	2.85	2.48	32.25	16.3
1980	0.70	0.99	1.94	2.41	1.84	3.20	3.56	4.76	3.22	2.02	0.90	3.06	28.6	16.6
MDO 50 Monthly Degree Days 1968	0.	0.	30.	89.	174.	509.	620.	647.	430.	166.	11.	0.	2676.	2380.
1969	0.	0.	5.	88.	272.	410.	654.	669.	390.	138.	0.	0.	2626.	2395.
1970	0.	0.	0.	127.	351.	517.	696.	651.	438.	154.	4.	0.	2938.	2653.
1980	0.	0.	0.	42.	306.	466.	718.	704.	391.	65.	0.	0.	2650.	2543.

APPENDIX D

```
      PROGRAM DRIVER (INPUT=65,OUTPUT,TAPE10=/500,TAPE20,TAPE30,
     +TAPE61=OUTPUT)
*
*
**********************************************************************
*                                                                    *
*                  DEFINITION OF CONSTANTS AND VARIABLES             *
*                                                                    *
* ATMDRES = ATMOSPHERIC DIFFUSION RESISTANCE   S CM**-1              *
* AVENRGY = AVERAGE LIGHT FLUX DENSITY INCIDENT AT TOP OF CANOPY     *
*           DURING PREVIOUS WEEK                   W M**-2           *
* BA      = CONSTANT                                                 *
* BB      = CONSTANT                                                 *
* BBDIST  = BEAN-BEAN PLANTING DISTANCE   M                          *
* BBMOVLP = MAXIMUM ALLOWABLE OVERLAP OF BEAN-BEAN CANOPIES   M       *
* BBOVLP  = OVERLAP OF THE BEAN-BEAN CANOPIES   M                    *
* BCHODMD = BEAN CARBOHYDRATE DEMAND FOR LONGTERM STORAGE   G         *
* BCPOOL  = BEAN SHORTTERM CARBOHYDRATE STORAGE   G                  *
* BCSTORE = BEAN LONGTERM CARBOHYDRATE STORAGE   G                   *
* BCUMPHD = BEAN CUMULATIVE PHOTOSYNTHESIS PER DAY   MG CO2          *
* BDRYFR  = BEAN FRUIT DRY WEIGHT   G                                *
* BDRYLF  = BEAN CANOPY LEAF DRY WEIGHT   G                          *
* BDRYRT  = BEAN ROOT DRY WEIGHT   G                                 *
* BDRYST  = BEAN STEM DRY WEIGHT   G                                 *
* BEXCOEF = BEAN CANOPY EXTINCTION COEFFICIENT                       *
* BFRDMD  = BEAN FRUIT DEMAND FUNCTION FOR PARTITIONING              *
*           CARBOHYDRATE   G                                         *
* BFRFRT  = BEAN FRESH FRUIT WEIGHT   KG                             *
* BFRINCR = BEAN FRUIT DRY MATTER INCREASE   G                       *
* BGRAREA = AREA UNDER THE BEAN CANOPY   M**2                        *
* BLAI    = BEAN LEAF AREA INDEX                                     *
* BLFAREA = BEAN CANOPY LEAF AREA   M**2                             *
* BLFDMD  = BEAN LEAF DEMAND FUNCTION FOR PARTITIONING               *
*           CARBOHYDRATE   G                                         *
* BLFINCR = BEAN LEAF DRY MATTER INCREASE   G                        *
* BLFRESP = BEAN LEAF DARK RESPIRATION RATE PER UNIT GROUND AREA     *
*                                            MG CO2 M**-2 S**-1      *
* BNFLAG  = FLAG TO DECLARE THAT BEAN-BEAN OVERLAP HAS REACHED THE   *
*           MAXIMUM ALLOWABLE DISTANCE                               *
* BNHIGHT = HEIGHT OF THE BEAN CANOPY   M                            *
* BNPLANT = BEAN PLANTING DATE IN MODEL DAYS                         *
* BNRADA  = BEAN CANOPY RADIUS IN THE DIRECTION OF THE ROW   M       *
* BNRADB  = BEAN RADIUS IN THE DIRECTION PERPENDICULAR TO THE ROW   M *
* BNSHADE = HORIZONTAL LENGTH OF THE BEAN CANOPY SHADOW   M          *
* BOVAREA = SUM OF OVERLAP GROUND AREA ON BOTH SIDES OF BEAN         *
*           CANOPY   M**2                                            *
* BOVFRCT = BEAN-BEAN OVERLAP AREA AS A FRACTION OF BEAN GROUND AREA *
* BPHSATE = BEAN NET PHOTOSYNTHATE EXPRESSED AS GLUCOSE   G          *
* BPNRATE = BEAN NET PHOTOSYNTHESIS RATE PER UNIT GROUND AREA        *
*                                            MG CO2 M**-2 S**-1      *
* BPOPHEC = BEAN POPULATION PER HECTARE                              *
* BPOPHEX = BEAN POPULATION PER HEXAGON                              *
* BRESP   = BEAN TOTAL DARK RESPIRATION RATE PER UNIT GROUND AREA    *
*                                            MG CO2 M**-2 S**-1      *
* BRFRDMD = BEAN RELATIVE FRUIT DEMAND FOR PARTITIONING OF           *
*           CARBOHYDRATE                                             *
* BRLFDMD = BEAN RELATIVE LEAF DEMAND FOR PARTITIONING OF            *
*           CARBOHYDRATE                                             *
* BRRTDMD = BEAN RELATIVE ROOT DEMAND FOR PARTITIONING OF            *
*           CARBOHYDRATE                                             *
* BRSTDMD = BEAN RELATIVE STEM DEMAND FOR PARTITIONING OF            *
```

```
*          CARBOHYDRATE
* BRTDMD  = BEAN ROOT DEMAND FUNCTION FOR PARTITIONING
*           CARBOHYDRATE   G
* BRTINCR = BEAN ROOT DRY MATTER INCREASE   G
* BSTDMD  = BEAN STEM DEMAND FUNCTION FOR PARTITIONING
*           CARBOHYDRATE   G
* BSTINCR = BEAN STEM DRY MATTER INCREASE   G
* BSTRESP = BEAN STRUCTURE DARK RESPIRATION RATE PER UNIT GROUND
*           AREA (ROOT, STEM AND FRUIT)          MG CO2 M**-2 S**-1
* BSUMDMD = BEAN SUM OF THE COMPONENT PARTITIONING DEMANDS FOR
*           CARBOHYDRATE   G
* BTRANS  = BEAN LEAF TRANSMISSION COEFFICIENT
* BTRLCTE = BEAN CARBOHYDRATE REMOVED FROM SHORTTERM STORAGE FOR
*           TRANSLOCATION TO THE VARIOUS COMPONENTS   G
* BUTILIZ = BEAN LEAF LIGHT UTILIZATION EFFICIENCY   MG CO2 J**-1
* BX      = CONSTANT
* BY      = CONSTANT
* BYLDHEC = BEAN YIELD PER HECTARE   KG HECTARE**-1
* BYLDHEX = BEAN YIELD PER HEXAGON   KG HEXAGON**-1
* BYLDM2  = BEAN YIELD PER UNIT AREA   KG M**-2
* CANDRES = CANOPY DIFFUSION RESISTANCE   S CM**-1
* COUNTER = COUNT OF NUMBER OF ITERATIONS DURING A PARTICULAR DAY
* CO2     = CO2 CONCENTRATION   MG CO2 M**-3
* CUMENDY = CUMULATIVE ENERGY OVER THE DAY   W M**-2
* CUMEVAP = CUMULATIVE EVAPOTRANSPIRATION   M
* CUMIRGN = CUMULATIVE IRRIGATION   M
* CUMRAIN = CUMULATIVE PRECIPITATION   M
* DAY     = DAYS AFTER COMMENCEMENT OF THE SIMULATION (FIRST DAY
*           IS DEFINED AS DAY 1)   DAY
* DELTA   = CHANGE OF SATURATION VAPOR PRESSURE WITH TEMPERATURE   MB
* DSWC    = CHANGE IN SOIL MOISTURE IN A GIVEN VOLUME OF SOIL
*                                                      M HR**-1
* DVOL    = CHANGE IN SOIL VOLUME OCCUPIED BY THE ROOT SYSTEM   M**3
* EBDRYLF = EFFECTIVE BEAN LEAF DRY WEIGHT DUE TO BEAN-BEAN
*           OVERLAP   G
* ECOUNT  = COUNT OF EVENT WHEN ENERGY EXCEEDS .01 , SET TO ZERO
*           EACH DAY WHEN COUNTER = U. USED TO COMPUTE S1 IN PHOTO.
* ENERGY  = LIGHT FLUX DENSITY INCIDENT AT TOP OF CANOPY   W M**-2
* ENSTORE = STORED VALUE OF ENERGY FOR THAT ITERATION   W M**-2
* EVAPOTN = ACTUAL EVAPOTRANSPIRATION RATE   M HR**-1
* GAMMA   = CONSTANT   MB
* HARVEST = BEAN HARVEST DATE IN MODEL DAYS
* HBBDIST = HALF THE BEAN-BEAN PLANTING DISTANCE   M
* HEXAREA = HEXAGON AREA   M**2
* HEXCIRC = HEXAGON CIRCUMFERENCE   M
* HEXPHEC = NUMBER OF HEXAGONS PER HECTARE
* HTTDIST = HALF THE TOMATO-TOMATO PLANTING DISTANCE   M
* I       = TOTAL NUMBER OF ITERATIONS IN THE RUN
* IBNDAY  = NUMBER OF BEAN DAYS AFTER BNPLANT
* IDAY    = VARIANT OF DAY USED IN THE WEATHER SUBROUTINE
* IHR     = SAME AS COUNTER.
* IMONTH  = VARIANT OF MONTH USED IN THE WEATHER SUBROUTINE
* IRRIGTN = IRRIGATION   M
* JDAY    = VARIANT OF DAY USED IN THE WEATHER SUBROUTINE
* JMONTH  = VARIANT OF MONTH USED IN THE WEATHER SUBROUTINE
* KOUNTER = SPECIAL VERSION OF COUNTER WHICH RUNS FROM 1 TO 8 AND IS
*           USED IN CALLING SHADE
* LFWPOTL = LEAF WATER POTENTIAL   BAR
* MBNRADB = MAXIMUM ALLOWABLE BEAN CANOPY RADIUS PERPENDICULAR TO
*           THE ROW   M
* MODE    = TYPE OF BEAN GROWTH
```

```
* MONTH   = MONTH OF THE YEAR
* PAR     = PHOTOSYNTHETICALLY ACTIVE RADIATION INCIDENT AT TOP OF
*           CANOPY   ERG CM**-2 S**-1
* POOLCHK = MINIMUM CARBOHYDRATE LEVEL ALLOWED IN SHORTTERM STORAGE  G
* RAIN    = PRECIPITATION  M
* RATIOE  = LESSER VALUE OF RATIOP AND RATIOT, USED TO SCALE DOWN
*           PHOTOSYNTHETIC RATE
* RATIOM  = ADJUSTMENT TO TOMATO PHOTOSYNTHETIC RATE DUE TO AGE OF
*           THE CANOPY
* RATIOP  = ADJUSTMENT TO PHOTOSYNTHETIC RATE DUE TO LEAF WATER
*           POTENTIAL DIFFERENCES FROM THE OPTIMUM
* RATIOT  = ADJUSTMENT TO PHOTOSYNTHETIC RATE DUE TO TEMPERATURE
*           DIFFERENCES FROM THE OPTIMUM
* RELHUM  = RELATIVE HUMIDITY
* RHMSAVE = STORED VALUE OF RELHUM TO ALLOW FOR MISSING VALUES IN
*           THE WEATHER DATA
* RTDEPTH = ROOT SYSTEM DEPTH   M
* S       = AVERAGE ENERGY RECEIVED DURING A 3 HOUR PERIOD FOR ONE
*           OF THE PREVIOUS 7 DAYS
* SHADE   = RATIO OF AN OBJECT"S SHADOW LENGTH TO THE HEIGHT OF
*           THE OBJECT
* SOILBD  = SOIL BULK DENSITY   G CM**-3
* STPNRTE = SHADED TOMATO NET PHOTOSYNTHESIS RATE PER UNIT GROUND
*           AREA    MG CO2 M**-2 S**-1
* SWC     = VOLUMETRIC SOIL WATER CONTENT
* SWPOT   = SOIL WATER POTENTIAL    BAR
* SYLDHEC = SUM OF THE YIELDS OF THE TWO SPECIES PER HECTARE   KG
* SYLDHEX = SUM OF THE YIELDS OF THE TWO SPECIES PER HEXAGON   KG
* SYLDM2  = SUM OF THE YIELDS OF THE TWO SPECIES PER UNIT AREA   KG
* TA      = CONSTANT
* TB      = CONSTANT
* TBMOVLP = MAXIMUM ALLOWABLE OVERLAP OF TOMATO-BEAN CANOPIES   M
* TBOVLP  = OVERLAP OF THE TOMATO-BEAN CANOPIES        M
* TCHODMD = TOMATO CARBOHYDRATE DEMAND FOR LONGTERM STORAGE   G
* TCPOOL  = TOMATO SHORTTERM CARBOHYDRATE STORAGE   G
* TCSTORE = TOMATO LONGTERM CARBOHYDRATE STORAGE   G
* TCUMPHD = TOMATO CUMULATIVE PHOTOSYNTHESIS PER DAY   MG CO2
* TDAY    = CONVERSION OF DAY TO REAL FOR RATIOM CALCULATION
* TDIAM   = TOMATO CANOPY DIAMETER   M
* TDRYFR  = TOMATO FRUIT DRY WEIGHT   G
* TDRYLF  = TOMATO CANOPY LEAF DRY WEIGHT   G
* TDRYRT  = TOMATO ROOT DRY WEIGHT   G
* TDRYST  = TOMATO STEM DRY WEIGHT   G
* TEMP    = DRY BULB TEMPERATURE   C
* TEXCOEF = TOMATO CANOPY EXTINCTION COEFFICIENT
* TFRDMD  = TOMATO FRUIT DEMAND FUNCTION FOR PARTITIONING
*           CARBOHYDRATE   G
* TFRINCR = TOMATO FRUIT DRY MATTER INCREASE   G
* TFRFRT  = TOMATO FRESH FRUIT WEIGHT   KG
* TGRAREA = AREA UNDER THE TOMATO CANOPY   M**2
* TGRSHDE = GROUND AREA OF THE TOMATO CANOPY SHADED BY THE
*           BEAN CANOPY   M**2
* TLAI    = TOMATO LEAF AREA INDEX
* TLFAREA = TOMATO CANOPY LEAF AREA   M**2
* TLFDMD  = TOMATO LEAF DEMAND FUNCTION FOR PARTITIONING
*           CARBOHYDRATE   G
* TLFINCR = TOMATO LEAF DRY MATTER INCREASE   G
* TLFRESP = TOMATO LEAF DARK RESPIRATION RATE PER UNIT GROUND AREA
*                                             MG CO2 M**-2 S**-1
* TMPSAVE = STORED VALUE OF TEMP TO ALLOW FOR MISSING VALUES IN THE
*           WEATHER DATA
```

```
* TOTLPOP = TOTAL PLANT POPULATION PER HECTARE                              *
* TPHSATE = TOMATO NET PHOTOSYNTHATE EXPRESSED AS GLUCOSE   G               *
* TPNRATE = TOMATO NET PHOTOSYNTHESIS RATE PER UNIT GROUND AREA             *
*                                              MG CO2 M**-2 S**-1           *
* TPOPLTN = TOMATO POPULATION PER HECTARE                                   *
* TRAD    = TOMATO CANOPY RADIUS    M                                       *
* TRESP   = TOMATO TOTAL DARK RESPIRATION RATE PER UNIT GROUND AREA         *
*                                              MG CO2 M**-2 S**-1           *
* TRFRDMD = TOMATO RELATIVE FRUIT DEMAND FOR PARTITIONING OF                *
*           CARBOHYDRATE                                                    *
* TRLFDMD = TOMATO RELATIVE LEAF DEMAND FOR PARTITIONING OF                 *
*           CARBOHYDRATE                                                    *
* TRRTDMD = TOMATO RELATIVE ROOT DEMAND FOR PARTITIONING OF                 *
*           CARBOHYDRATE                                                    *
* TRSTDMD = TOMATO RELATIVE STEM DEMAND FOR PARTITIONING OF                 *
*           CARBOHYDRATE                                                    *
* TRTDMD  = TOMATO ROOT DEMAND FUNCTION FOR PARTITIONING                    *
*           CARBOHYDRATE   G                                                *
* TRTINCR = TOMATO ROOT DRY MATTER INCREASE   G                             *
* TSHADE  = HORIZONTAL ENCROACHMENT DISTANCE OF THE BEAN SHADOW             *
*           ONTO THE TOMATO GROUND AREA   M                                 *
* TSTDMD  = TOMATO STEM DEMAND FUNCTION FOR PARTITIONING                    *
*           CARBOHYDRATE   G                                                *
* TSTINCR = TOMATO STEM DRY MATTER INCREASE   G                             *
* TSTRESP = TOMATO STRUCTURE DARK RESPIRATION RATE PER UNIT GROUND          *
*           AREA (ROOT, STEM AND FRUIT)        MG CO2 M**-2 S**-1           *
* TSUMDMD = TOMATO SUM OF THE COMPONENT PARTITIONING DEMANDS FOR            *
*           CARBOHYDRATE   G                                                *
* TTDIST  = TOMATO-TOMATO PLANTING DISTANCE   M                             *
* TTRANS  = TOMATO LEAF TRANSMISSION COEFFICIENT                            *
* TTRLCTE = TOMATO CARBOHYDRATE REMOVED FROM SHORTTERM STORAGE FOR          *
*           TRANSLOCATION TO THE VARIOUS COMPONENTS   G                     *
* TUTILIZ = TOMATO LEAF LIGHT UTILIZATION EFFICIENCY   MG CO2 J**-1         *
* TX      = CONSTANT                                                        *
* TY      = CONSTANT                                                        *
* TYLDHEC = TOMATO YIELD PER HECTARE   KG HECTARE**-1                       *
* TYLDHEX = TOMATO YIELD PER HEXAGON   KG HEXAGON**-1                       *
* TYLDM2  = TOMATO YIELD PER UNIT AREA   KG M**-2                           *
* VAPSAT  = SATURATED VAPOR PRESSURE AT CURRENT TEMPERATURE   BAR           *
* VAPTEMP = VAPOR PRESSURE AT CURRENT TEMPERATURE   BAR                     *
* VOLS1   = SOIL VOLUME OCCUPIED BY ROOT SYSTEM   M**3                      *
* VOLS2   = NEW VALUE OF VOLS1                                              *
* WINDCON = CONSTANT                                                        *
* WINDSPD = WIND SPEED    M S**-1                                           *
* WNDSAVE = STORED VALUE OF WINDSPD TO ALLOW FOR MISSING VALUES IN          *
*           THE WEATHER DATA                                                *
*                                                                           *
*****************************************************************************
*
*
* ESTABLISH REAL AND INTEGER VARIABLES
*
      INTEGER COUNTER,DAY,PRINTYP,XCOUNTR,XDAY,XI,XMONTH,XDATE,XJMONTH,
     +XJDATE,XIMONTH,XIDATE,DATE,BNPLANT,HARVEST,XBNPLAN,XHARVES
      REAL MBNRADB,LFWPOTL
*
*
* ESTABLISH ALL COMMON BLOCKS. "MAIN" IS THE PRIMARY COMMON BLOCK FOR
* TRANSFER OF VARIABLE VALUES BETWEEN SUBROUTINES. ALL OTHER COMMON
* BLOCKS ARE USED FOR STORING VARIABLE VALUES FOR PRINTING.
*
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      COMMON /MAIN/ BBDIST,BDRYFR,BDRYLF,BDRYRT,BDRYST,BGRAREA,BLAI,
     +BNRADA,BNRADB,BPHSATE,COUNTER,ENERGY(24),HTTDIST,RAIN,
     +RELHUM(24),TDRYFR,TDRYLF,TDRYRT,TDRYST,TEMP(24),TGRAREA,TLAI,
     +TPHSATE,TRAD,TTDIST,WINDSPD(24),I,SHADE(101,8),IHR,DAY,LFWPOTL,
     +HBBDIST,MONTH,DATE,IMONTH,IDATE,JMONTH,JDATE,BNPLANT,HARVEST
*
      COMMON /WATER/XCANDRE(180),XCUMEVA(180),XCUMIRG(180),XCUMRAI(180),
     +XDELTA(180),XDSWC(180),XDVOL(180),XEVAPOT(180),XLFWPOT(180),
     +XRTDEPT(180),XSWC(180),XSWPOT(180),XVOLS1(180),XVAPSAT(180),
     +XVAPTEM(180)
*
      COMMON /PHOTO/XDAY(180),XSHADE(180),XCOUNTR(180),XAVENGY(180),
     +XBCUMPH(180),XBLFRSP(180),XBNHIGH(180),XBNSHDE(180),XBPHSTE(180),
     +XBPNRTE(180),XBRESP(180),XENERGY(180),XS1(180),XS2(180),XS3(180),
     +XS4(180),XS5(180),XS6(180),XS7(180),XSTPNRT(180),XTCUMPH(180),
     +XTGRSHD(180),XTLFRSP(180),XTPHSTE(180),XTPNRTE(180),XTRESP(180),
     +XTSHADE(180),XRAIN(180),XRELHUM(180),XTEMP(180),XWINDSP(180),
     +XI(180),XMONTH(180),XDATE(180),XJMONTH(180),XJDATE(180),
     +XIMONTH(180),XIDATE(180),XBNPLAN(180),XHARVES(180)
*
      COMMON /TOMPART/XPOOLCH(180),XTCHODM(180),
     +XTCPOOL(180),XTCSTOR(180),XTDRYFR(180),XTDRYRT(180),XTDRYLF(180),
     +XTDRYST(180),XTFRDMD(180),XTFRINC(180),XTLFDMD(180),XTLFINC(180),
     +XTPHSAT(180),XTRFRDM(180),XTRLFDM(180),XTRRTDM(180),XTRSTDM(180),
     +XTRTDMD(180),XTRTINC(180),XTSTDMD(180),XTSTINC(180),XTSUMDM(180),
     +XTTRLCT(180)
*
      COMMON /BNPART/XPOOLCK(180),XBCHODM(180),XBCPOOL(180),
     +XBCSTOR(180),XBDRYFR(180),XBDRYRT(180),XBDRYST(180),XBDRYLF(180),
     +XBFRDMD(180),XBFRINC(180),XBLFDMD(180),XBLFINC(180),XBPHSAT(180),
     +XBRFRDM(180),XBRLFDM(180),XBRRTDM(180),XBRSTDM(180),XBRTDMD(180),
     +XBRTINC(180),XBSTDMD(180),XBSTINC(180),XBSUMDM(180),XBTRLCT(180)
*
      COMMON /CANOPY/IMODE(180),XBNRADA(180),XBNRADB(180),XBGRARA(180),
     +XBBDRYL(180),XBLFARA(180),XBLAI(180),XBBOVLP(180),
     +XBOVARA(180),XBOVFRC(180),XBNFLAG(180),XTRAD(180),XTGRARA(180),
     +XTLFARA(180),XTLAI(180),XTBOVLP(180)
*
      COMMON /YIELD/XBFRFRT(180),XBPCPHC(180),XBPOPHX(180),XBYLDHC(180),
     +XBYLDHX(180),XBYLDM2(180),XHEXARE(180),XHEXCIR(180),XHEXPHE(180),
     +XSYLDHC(180),XSYLDHX(180),XSYLDM2(180),XTFRFRT(180),
     +XTOTLPO(180),XTPOPLT(180),XTYLDHC(180),XTYLDHX(180),XTYLDM2(180),
     +XBBDIST(180),XHTTDIS(180)
*
*
*
* READ IN SHADE DATA
*
      DATA((SHADE(M,N),N=1,8),M=1,10)/
     +0.,5.5,1.5,.4,.7,2.2,7.,0.,0.,5.5,1.5,.4,.7,2.2,7.,0.,
     +0.,5.5,1.5,.4,.7,2.2,7.,0.,0.,5.5,1.5,.4,.7,2.2,7.,0.,
     +0.,5.5,1.5,.4,.7,2.2,7.,0.,0.,5.5,1.5,.4,.7,2.2,7.,0.,
     +0.,5.5,1.5,.4,.7,2.2,7.,0.,0.,5.5,1.5,.4,.7,2.2,7.,0.,
     +0.,5.5,1.5,.4,.7,2.2,7.,0.,0.,5.5,1.5,.4,.7,2.2,7.,0./
      DATA((SHADE(M,N),N=1,8),M=11,20)/
     +0.,5.5,1.5,.4,.7,2.2,7.,0.,0.,5.5,1.5,.4,.7,2.2,7.,0.,
     +0.,5.5,1.5,.4,.7,2.2,7.,0.,0.,5.5,1.5,.4,.7,2.2,7.,0.,
     +0.,5.5,1.5,.4,.7,2.2,7.,0.,0.,5.5,1.5,.4,.8,2.5,9.,0.,
     +0.,5.5,1.5,.4,.8,2.5,9.,0.,0.,5.5,1.5,.4,.8,2.5,9.,0.,
     +0.,5.5,1.5,.4,.8,2.5,9.,0.,0.,5.5,1.5,.4,.8,2.5,9.,0./
      DATA((SHADE(M,N),N=1,8),M=21,30)/
```

```
     +0.,5.5,1.5,.4,.8,2.5,9.,0.,0.,5.5,1.5,.4,.8,2.5,9.,0.,
     +0.,5.5,1.5,.4,.8,2.5,9.,0.,0.,5.5,1.5,.4,.8,2.5,9.,0.,
     +0.,5.5,1.5,.4,.8,2.5,9.,0.,0.,5.5,1.5,.4,.8,2.5,9.,0.,
     +0.,5.5,1.5,.4,.8,2.5,9.,0.,0.,5.5,1.5,.4,.8,2.5,9.,0.,
     +0.,5.5,1.5,.4,.8,2.5,9.,0.,0.,5.5,1.5,.4,.8,2.5,9.,0./
      DATA((SHADE(M,N),N=1,8),M=31,40)/
     +0.,9.,1.7,.5,.9,2.2,0.,0.,0.,9.,1.7,.5,.9,2.2,0.,0.,
     +0.,9.,1.7,.5,.9,2.2,0.,0.,0.,9.,1.7,.5,.9,2.2,0.,0.,
     +0.,9.,1.7,.5,.9,2.2,0.,0.,0.,9.,1.7,.5,.9,2.2,0.,0.,
     +0.,9.,1.7,.5,.9,2.2,0.,0.,0.,9.,1.7,.5,.9,2.2,0.,0.,
     +0.,9.,1.7,.5,.9,2.2,0.,0.,0.,9.,1.7,.5,.9,2.2,0.,0./
      DATA((SHADE(M,N),N=1,8),M=41,50)/
     +0.,9.,1.7,.5,.9,2.2,0.,0.,0.,9.,1.7,.5,.9,2.2,0.,0.,
     +0.,9.,1.7,.5,.9,2.2,0.,0.,0.,9.,1.7,.5,.9,2.2,0.,0.,
     +0.,9.,1.7,.5,.9,2.2,0.,0.,0.,0.,2.,.6,1.,2.,0.,0.,
     +0.,0.,2.,.6,1.,2.,0.,0.,0.,0.,2.,.6,1.,2.,0.,0.,
     +0.,0.,2.,.6,1.,2.,0.,0.,0.,0.,2.,.6,1.,2.,0.,0./
      DATA((SHADE(M,N),N=1,8),M=51,60)/
     +0.,0.,2.,.6,1.,2.,0.,0.,0.,0.,2.,.6,1.,2.,0.,0.,
     +0.,0.,2.,.6,1.,2.,0.,0.,0.,0.,2.,.6,1.,2.,0.,0.,
     +0.,0.,2.,.6,1.,2.,0.,0.,0.,0.,2.,.6,1.,2.,0.,0.,
     +0.,0.,2.,.6,1.,2.,0.,0.,0.,0.,2.,.6,1.,2.,0.,0.,
     +0.,0.,2.,.6,1.,2.,0.,0.,0.,0.,2.,.6,1.,2.,0.,0./
      DATA((SHADE(M,N),N=1,8),M=61,70)/
     +0.,0.,2.,.8,1.1,3.5,0.,0.,0.,0.,2.,.8,1.1,3.5,0.,0.,
     +0.,0.,2.,.8,1.1,3.5,0.,0.,0.,0.,2.,.8,1.1,3.5,0.,0.,
     +0.,0.,2.,.8,1.1,3.5,0.,0.,0.,0.,2.,.8,1.1,3.5,0.,0.,
     +0.,0.,2.,.8,1.1,3.5,0.,0.,0.,0.,2.,.8,1.1,3.5,0.,0.,
     +0.,0.,2.,.8,1.1,3.5,0.,0.,0.,0.,2.,.8,1.1,3.5,0.,0./
      DATA((SHADE(M,N),N=1,8),M=71,80)/
     +0.,0.,2.,.8,1.1,3.5,0.,0.,0.,0.,2.,.8,1.1,3.5,0.,0.,
     +0.,0.,2.,.8,1.1,3.5,0.,0.,0.,0.,2.,.8,1.1,3.5,0.,0.,
     +0.,0.,2.,.8,1.1,3.5,0.,0.,0.,0.,2.,1.,1.2,5.,0.,0.,
     +0.,0.,2.,1.,1.2,5.,0.,0.,0.,0.,2.,1.,1.2,5.,0.,0.,
     +0.,0.,2.,1.,1.2,5.,0.,0.,0.,0.,2.,1.,1.2,5.,0.,0./
      DATA((SHADE(M,N),N=1,8),M=81,90)/
     +0.,0.,2.,1.,1.2,5.,0.,0.,0.,0.,2.,1.,1.2,5.,0.,0.,
     +0.,0.,2.,1.,1.2,5.,0.,0.,0.,0.,2.,1.,1.2,5.,0.,0.,
     +0.,0.,2.,1.,1.2,5.,0.,0.,0.,0.,2.,1.,1.2,5.,0.,0.,
     +0.,0.,2.,1.,1.2,5.,0.,0.,0.,0.,2.,1.,1.2,5.,0.,0.,
     +0.,0.,2.,1.,1.2,5.,0.,0.,0.,0.,2.,1.,1.2,5.,0.,0./
      DATA((SHADE(M,N),N=1,8),M=91,101)/
     +0.,0.,3.,1.5,2.,8.,0.,0.,0.,0.,3.,1.5,2.,8.,0.,0.,
     +0.,0.,3.,1.5,2.,8.,0.,0.,0.,0.,3.,1.5,2.,8.,0.,0.,
     +0.,0.,3.,1.5,2.,8.,0.,0.,0.,0.,3.,1.5,2.,8.,0.,0.,
     +0.,0.,3.,1.5,2.,8.,0.,0.,0.,0.,3.,1.5,2.,8.,0.,0.,
     +0.,0.,3.,1.5,2.,8.,0.,0.,0.,0.,3.,1.5,2.,8.,0.,0.,
     +0.,0.,3.,1.5,2.,8.,0.,0./
*
      CALL DISCON(6LOUTPUT)
      REWIND 61
      CALL CONNEC(6LOUTPUT)
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
* RETURN TO THIS POINT IF A FURTHER RUN IS REQUIRED
*
 1000 CONTINUE
      REWIND 10
      REWIND 20
      REWIND 30
```

```
*
* INITIALIZE ALL NECESSARY VARIABLES AND CONSTANTS.
*
      BBDIST=.05
      BNPLANT=1
      COUNTER=0
      HARVEST=52
      PRINTYP=1
      TTDIST=.8
      MBNRADB=.327 + .632*ALOG10(TTDIST)
*
*
* CONFIRM INITIAL VALUES OF VARIABLES WHICH MAY BE CHANGED. ASK FOR
* ANY NEW VALUES.
*
      PRINT 101
 101  FORMAT(*0*,5X,*THESE ARE THE INITIAL VALUES*)
      PRINT 102, TTDIST
 102  FORMAT(*0*,10X,*TOMATO-TOMATO DISTANCE IN METERS*,F10.2)
      PRINT 103, BBDIST
 103  FORMAT(*0*,10X,*BEAN-BEAN DISTANCE IN METERS*,F14.2)
      PRINT 104, BNPLANT
 104  FORMAT(*0*,10X,*BEAN PLANTING DATE IN MODEL DAYS*,I10)
      PRINT 105, HARVEST
 105  FORMAT(*0*,10X,*BEAN HARVEST DATE IN MODEL DAYS*,I11)
      PRINT 106, PRINTYP
 106  FORMAT(*0*,10X,*PRINT TYPE ( 1 = DAILY AT 1200 AND 2400 HR, 2 = DA
     +ILY AT 2400 HR, 3 = FINAL VALUES ONLY, 4 = FINAL YIELD ONLY )*,I3)
      PRINT 107
 107  FORMAT(*0*,5X,*DO YOU WANT TO MAKE ANY CHANGES, YES OR NO?*)
      READ 108, I1
 108  FORMAT(A2)
      IF(I1.EQ.2HNO) GO TO 129
      PRINT 109
 109  FORMAT(*0*,5X,*CHANGE TOMATO-TOMATO DISTANCE, YES OR NO?*)
      READ 110, I2
 110  FORMAT(A2)
      IF(I2.EQ.2HNO) GO TO 112
      PRINT 111
 111  FORMAT(*0*,10X,*TYPE NEW VALUE OF TTDIST ( IN METERS )*)
      READ*, TTDIST
 112  PRINT 113
 113  FORMAT(*0*,5X,*CHANGE BEAN-BEAN DISTANCE, YES OR NO?*)
      READ 114, I3
 114  FORMAT(A2)
      IF(I3.EQ.2HNO) GO TO 116
      PRINT 115
 115  FORMAT(*0*,10X,*TYPE NEW VALUE OF BBDIST ( IN METERS )*)
      READ*,BBDIST
 116  PRINT 117
 117  FORMAT(*0*,5X,*CHANGE BEAN PLANTING DATE, YES OR NO?*)
      READ 118, I4
 118  FORMAT(A2)
      IF(I4.EQ.2HNO) GO TO 120
      PRINT 119
 119  FORMAT(*0*,10X,*TYPE NEW VALUE OF BNPLANT ( IN MODEL DAYS )*)
      READ*, BNPLANT
 120  PRINT 121
 121  FORMAT(*0*,5X,*CHANGE BEAN HARVEST DATE, YES OR NO?*)
      READ 122, I5
 122  FORMAT(A2)
```

```
      IF(I5.EQ.2HNO) GO TO 124
      PRINT 123
 123  FORMAT(*C*,10X,*TYPE NEW VALUE OF BEAN HARVEST ( IN MODEL DAYS )*)
      READ*,HARVEST
 124  PRINT 125
 125  FORMAT(*0*,5X,*CHANGE PRINT TYPE, YES OR NO?*)
      READ 126, I6
 126  FORMAT(A2)
      IF(I6.EQ.2HNO) GO TO 129
      PRINT 127
 127  FORMAT(*0*,10X,*TYPE NEW VALUE OF PRINTYP*)
      READ*,PRINTYP
*
 129  HBBDIST=BBDIST/2.
      HTTDIST=TTDIST/2.
*
      PRINT 130
 130  FORMAT(*0*,*++++++++++++++++++++  PROGRAM EXECUTION COMMENCES  +++
     ++++++++++++++++++*)
*
* THE FOLLOWING DO LOOP CONTROLS THE SIMULATION. VARIABLE VALUES ARE
* STORED EACH 12 HOURS AND PRINTED IN ONE BLOCK AFTER THE RUN IS
* COMPLETED.
*
************************************************************************
*                                                                      *
*                                                                      *
* COMMENCE DO LOOP
*
      I=0
*
      DO 100 K=1,81
*
           DAY=K
*
           CALL WEATHER
*
                DO 200 IHR=1,24
*
                     COUNTER=IHR
*
                     IF(COUNTER.EQ.12.OR.COUNTER.EQ.24) I=I+1
*
                     CALL WATER
*
                     CALL PHOTO
*
                     CALL BNPART
*
                     CALL TOMPART
*
                     CALL CANOPY
*
                     CALL YIELD
*
 200            CONTINUE
 100  CONTINUE
*                                                                      *
*                                                                      *
************************************************************************
*
```

```
*
* PRINT HOURLY, DAILY OR SEASONAL VALUES AS REQUESTED BY PRINTYP
*
      PRINT*,"CONTINUE OUTPUT ON DECWRITER??"
      READ 1234,IANS
 1234 FORMAT(A1)
      IF(IANS.EQ.1HY) GO TO 1235
      CALL DISCON (6LOUTPUT)
 1235 CONTINUE
      IF(PRINTYP.EQ.1) GO TO 900
      IF(PRINTYP.EQ.2) GO TO 910
      IF(PRINTYP.EQ.3) GO TO 920
      IF(PRINTYP.EQ.4) GO TO 925
*
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*
*                         *********************
*                         *                   *
*                         *  12 HOURLY PRINT  *
*                         *                   *
*                         *********************
*
* THIS SECTION PRINTS VARIABLE VALUES EVERY 1200 HR AND 2400 HR.
*
* PRINT FOR SUBROUTINE PHOTO
*
 900  PRINT 150
 150  FORMAT(*112 HOURLY PRINT FOR SUBROUTINE PHOTO*)
      PRINT 21
 21   FORMAT(*-DAY  I  COUNTER ENERGY TEMP RAIN RELHUM WINDSPD MONTH DAT
     +E JMONTH JDATE IMONTH IDATE         I  BNPLANT HARVEST*)
      PRINT 22,(XDAY(I),XI(I),XCOUNTR(I),XENERGY(I),XTEMP(I),XRAIN(I),
     +XRELHUM(I),XWINDSP(I),XMONTH(I),XDATE(I),XJMONTH(I),XJDATE(I),
     +XIMONTH(I),XIDATE(I),XI(I),XBNPLAN(I),XHARVES(I),I=1,162,161)
 22   FORMAT(I3,2X,I3,1X,I4,4X,F5.1,2X,F4.1,1X,F4.2,1X,F5.2,1X,F7.1,2X,
     +I4,2X,I3,4X,I4,1X,I4,2X,I4,3X,I4,3X,I8,4X,I2,6X,I2)
      PRINT 701
 701  FORMAT(*1  I  DAY CANDRES  DELTA  EVAPOTN  VOLS1    DVOL    DSWC
     +  SWC    RTDEPTH    SWPOT  LFWPOTL CUMIRGN CUMRAIN CUMEVAP  VAPSAT V
     +APTEMP*)
      PRINT 702,(XI(I),XDAY(I),XCANDRE(I),XDELTA(I),XEVAPOT(I),XVOLS1(I)
     +,XDVOL(I),XDSWC(I),XSWC(I),XRTDEPT(I),XSWPOT(I),XLFWPOT(I),
     +XCUMIRG(I),XCUMRAI(I),XCUMEVA(I),XVAPSAT(I),XVAPTEM(I),I=1,162)
 702  FORMAT(1X,I3,1X,I3,1X,F7.2,1X,F7.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,
     +F7.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,F7.2,1X,F7.2,1X,F7.2,1X,
     +F7.3,1X,F7.2)
      PRINT 23
 23   FORMAT(*1  I  DAY ENERGY AVENRGY   S1      S2      S3      S4      S5
     +     S6      S7    TLFRESP TPNRATE TPHSATE TCUMPHD*)
      PRINT 24,(XI(I),XDAY(I),XENERGY(I),XAVENGY(I),XS1(I),XS2(I),
     +XS3(I),XS4(I),XS5(I),XS6(I),XS7(I),XTLFRSP(I),XTPNRTE(I),
     +XTPHSTE(I),XTCUMPH(I),I=1,162)
 24   FORMAT(1X,I3,1X,I3,1X,F6.2,1X,F7.2,1X,F6.2,1X,F6.2,1X,F6.2,1X,
     +F6.2,1X,F6.2,1X,F6.2,1X,F6.2,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4)
      PRINT 25
 25   FORMAT(*1  I  DAY BLFRESP BPNRATE BPHSATE BCUMPHD BNHIGHT BNSHADE
     +TSHADE TGRSHDE STPNRTE TPNRTE SHADE TRESP BRESP*)
      PRINT 26,(XI(I),XDAY(I),XBLFRSP(I),XBPNRTE(I),XBPHSTE(I),
     +XBCUMPH(I),XBNHIGH(I),XBNSHDE(I),XTSHADE(I),XTGRSHD(I),
```

```
     +XSTPNRT(I),XTPNRTE(I),XSHADE(I),XTRESP(I),XBRESP(I),I=1,162)
 26   FORMAT(1X,I3,1X,I3,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.3,1X,
     +F7.3,1X,F6.3,1X,F7.5,1X,F7.4,1X,F7.4,1X,F4.2,1X,F5.3,1X,F5.3)
*
* PRINT FOR SUBROUTINE BNPART
*
      PRINT 151
 151  FORMAT(*112 HOURLY PRINT FOR SUBROUTINE BNPART*)
      PRINT 27
 27   FORMAT(*- I  DAY COUNTER BPHSATE BCSTORE POOLCHK BCHODMD BCPOOL BT
     +RLCTE BFRDMD BLFDMD BRTDMD BSTDMD BRFRDMD BRLFDMD BRRTDMD BRSTDMD 
     +BSUMDMD*)
      PRINT 28,(XI(I),XDAY(I),XCOUNTR(I),XBPHSAT(I),XBCSTOR(I),XPOOLCK(I
     +),XBCHODM(I),XBCPOOL(I),XBTRLCT(I),XBFRDMD(I),XBLFDMD(I),XBRTDMD(I
     +),XBSTDMD(I),XBRFRDM(I),XBRLFDM(I),XBRRTDM(I),XBRSTDM(I),XBSUMDM(I
     +),I=1,162)
 28   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F6.3,1X,F7.4,1X,F6.2,1X,F6.2,1X,F6.3,1X,F6.2,1X,F7.4,1X,
     +F7.4,1X,F7.4,1X,F7.4,1X,F7.3)
      PRINT 29
 29   FORMAT(*1 I  DAY COUNTER BFRINCR BLFINCR BRTINCR BSTINCR BDRYFR BD
     +RYLF BDRYRT BDRYST*)
      PRINT 30,(XI(I),XDAY(I),XCOUNTR(I),XBFRINC(I),XBLFINC(I),XBRTINC(I
     +),XBSTINC(I),XBDRYFR(I),XBDRYLF(I),XBDRYRT(I),XBDRYST(I),
     +I=1,162)
 30   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F6.2,1X,F6.2,1X,F6.2,1X,F6.2)
*
* PRINT FOR SUBROUTINE TOMPART
*
      PRINT 152
 152  FORMAT(*112 HOURLY PRINT FOR SUBROUTINE TOMPART*)
      PRINT 31
 31   FORMAT(*- I  DAY COUNTER TPHSATE TCSTORE POOLCHK TCHODMD TCPOOL TT
     +RLCTE TFRDMD TLFDMD TRTDMD TSTDMD TRFRDMD TRLFDMD TRRTDMD TRSTDMD 
     +TSUMDMD*)
      PRINT 32,(XI(I),XDAY(I),XCOUNTR(I),XTPHSAT(I),XTCSTOR(I),XPOOLCH(I
     +),XTCHODM(I),XTCPOOL(I),XTTRLCT(I),XTFRDMD(I),XTLFDMD(I),XTRTDMD(I
     +),XTSTDMD(I),XTRFRDM(I),XTRLFDM(I),XTRRTDM(I),XTRSTDM(I),XTSUMDM(I
     +),I=1,162)
 32   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F6.3,1X,F7.4,1X,F6.2,1X,F6.2,1X,F6.3,1X,F6.2,1X,F7.4,1X,
     +F7.4,1X,F7.4,1X,F7.4,1X,F7.3)
      PRINT 33
 33   FORMAT(*1 I  DAY COUNTER TFRINCR TLFINCR TRTINCR TSTINCR TDRYFR TD
     +RYLF TDRYRT TDRYST*)
      PRINT 34,(XI(I),XDAY(I),XCOUNTR(I),XTFRINC(I),XTLFINC(I),XTRTINC(I
     +),XTSTINC(I),XTDRYFR(I),XTDRYLF(I),XTDRYRT(I),XTDRYST(I),
     +I=1,162)
 34   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F7.4,1X,F6.2,1X,F6.2,1X,F6.2,1X,F6.2)
*
* PRINT FOR SUBROUTINE CANOPY
*
      PRINT 153
 153  FORMAT(*112 HOURLY PRINT FOR SUBROUTINE CANOPY*)
      PRINT 35
 35   FORMAT(*- I  DAY COUNTER MODE BNRADA BNRADB BGRAREA BDRYLF EBDRYLF
     + BLFAREA   BLAI BBOVLP BOVAREA BOVFRCT BNFLAG*)
      PRINT 36,(XI(I),XDAY(I),XCOUNTR(I),IMODE(I),XBNRADA(I),XBNRADB(I),
     +XBGRARA(I),XBDRYLF(I),XEBDRYL(I),XBLFARA(I),XBLAI(I),XBBOVLP(I),
```

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     +XBOVARA(I),XBOVFRC(I),XBNFLAG(I),I=1,162)
 36   FORMAT(1X,I3,1X,I2,4X,I2,5X,I1,2X,F6.3,1X,F6.3,1X,F7.5,1X,
     +F6.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,F6.3,1X,F7.3,1X,F7.5,1X,F6.2)
      PRINT 37
 37   FORMAT(*1 I  TRAD TGRAREA TDRYLF TLFAREA TLAI TBOVLP*)
      PRINT 38,(XI(I),XTRAD(I),XTGRARA(I),XTDRYLF(I),XTLFARA(I),
     +XTLAI(I),XTBOVLP(I),I=1,162)
 38   FORMAT(1X,I3,F4.2,1X,F7.3,1X,F6.1,1X,F7.3,1X,F4.1,1X,F6.3)
*
* PRINT FOR SUBROUTINE YIELD
*
      PRINT 154
 154  FORMAT(*112 HOURLY PRINT FOR SUBROUTINE YIELD*)
      PRINT 39
 39   FORMAT(*- I  DAY COUNTER HTTDIST BBDIST HEXAREA HEXPHEC HEXCIRC TP
     +OPLTN BPOPHEX BPOPHEC TOTLPOP*)
      PRINT 40,(XI(I),XDAY(I),XCOUNTR(I),XHTTDIS(I),XBBDIST(I),
     +XHEXARE(I),XHEXPHE(I),XHEXCIR(I),XTPOPLT(I),XBPOPHX(I),XBPOPHC(I),
     +XTOTLPO(I),I=1,162,161)
 40   FORMAT(1X,I3,1X,I2,3X,I2,6X,F4.2,3X,F4.2,3X,F5.3,3X,
     +F6.0,1X,F7.2,1X,F7.0,1X,F7.0,1X,F7.0,1X,F7.0)
      PRINT 41
 41   FORMAT(*1 I  DAY COUNTER BFRFRT BYLDHEX BYLDM2 BYLDHEC TFRFRT TYLD
     +HEX TYLDM2 TYLDHEC SYLDHEX SYLDM2 SYLDHEC*)
      PRINT 42,(XI(I),XDAY(I),XCOUNTR(I),XBFRFRT(I),XBYLDHX(I),
     +XBYLDM2(I),XBYLDHC(I),XTFRFRT(I),XTYLDHX(I),XTYLDM2(I),
     +XTYLDHC(I),XSYLDHX(I),XSYLDM2(I),XSYLDHC(I),I=1,162)
 42   FORMAT(1X,I3,1X,I2,3X,I2,4X,F6.3,1X,F7.3,1X,F6.3,1X,F7.0,1X,
     +F6.3,1X,F7.3,1X,F6.3,1X,F7.0,1X,F7.3,1X,F6.3,1X,F7.0)
*
      GO TO 930
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*
*                          *****************
*                          *               *
*                          *  DAILY PRINT  *
*                          *               *
*                          *****************
*
* THIS SECTION PRINTS VARIABLE VALUES ONCE PER DAY AT 2400 HR.
*
* PRINT FOR SUBROUTINE PHOTO
*
 910  PRINT 155
 155  FORMAT(*1DAILY PRINT FOR SUBROUTINE PHOTO*)
      PRINT 43
 43   FORMAT(*-DAY  I  COUNTER ENERGY TEMP RAIN RELHUM WINDSPD MONTH DAT
     +E JMONTH JDATE IMONTH IDATE          I  BNPLANT HARVEST*)
      PRINT 44,(XDAY(I),XI(I),XCOUNTR(I),XENERGY(I),XTEMP(I),XRAIN(I),
     +XRELHUM(I),XWINDSP(I),XMONTH(I),XDATE(I),XJMONTH(I),XJDATE(I),
     +XIMONTH(I),XIDATE(I),XI(I),XBNPLAN(I),XHARVES(I),I=2,162,160)
 44   FORMAT(I3,2X,I3,1X,I4,4X,F5.1,2X,F4.1,1X,F4.2,1X,F5.2,1X,F7.1,2X,
     +I4,2X,I3,4X,I4,1X,I4,2X,I4,3X,I4,3X,I8,4X,I2,6X,I2)
      PRINT 703
 703  FORMAT(*1  I  DAY CANDRES   DELTA  EVAPOTN  VOLS1    DVOL    DSWC
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     +  SWC   RTDEPTH   SWPOT  LFWPOTL CUMIRGN CUMRAIN CUMEVAP  VAPSAT V
     +APTEMP*)
      PRINT 704,(XI(I),XDAY(I),XCANDRE(I),XDELTA(I),XEVAPOT(I),XVOLS1(I)
     +,XDVOL(I),XDSWC(I),XSWC(I),XRTDEPT(I),XSWPOT(I),XLFWPOT(I),
     +XCUMIRG(I),XCUMRAI(I),XCUMEVA(I),XVAPSAT(I),XVAPTEM(I),I=2,162,2)
 704  FORMAT(1X,I3,1X,I3,1X,F7.2,1X,F7.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,
     +F7.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,F7.2,1X,F7.2,1X,F7.2,1X,
     +F7.3,1X,F7.2)
      PRINT 45
 45   FORMAT(*1  I  DAY ENERGY AVENRGY   S1     S2     S3     S4     S5
     +   S6     S7   TLFRESP TPNRATE TPHSATE TCUMPHD*)
      PRINT 46,(XI(I),XDAY(I),XENERGY(I),XAVENGY(I),XS1(I),XS2(I),
     +XS3(I),XS4(I),XS5(I),XS6(I),XS7(I),XTLFRSP(I),XTPNRTE(I),
     +XTPHSTE(I),XTCUMPH(I),I=2,162,2)
 46   FORMAT(1X,I3,1X,I3,1X,F6.2,1X,F7.2,1X,F6.2,1X,F6.2,1X,F6.2,1X,
     +F6.2,1X,F6.2,1X,F6.2,1X,F6.2,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4)
      PRINT 47
 47   FORMAT(*1  I  DAY BLFRESP BPNRATE BPHSATE BCUMPHD BNHIGHT BNSHADE
     +TSHADE TGRSHDE STPNRTE TPNRTE SHADE TRESP BRESP*)
      PRINT 48,(XI(I),XDAY(I),XBLFRSP(I),XBPNRTE(I),XBPHSTE(I),
     +XBCUMPH(I),XBNHIGH(I),XBNSHDE(I),XTSHADE(I),XTGRSHD(I),
     +XSTPNRT(I),XTPNRTE(I),XSHADE(I),XTRESP(I),XBRESP(I),I=2,162,2)
 48   FORMAT(1X,I3,1X,I3,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.3,1X,
     +F7.3,1X,F6.3,1X,F7.5,1X,F7.4,1X,F7.4,1X,F4.2,1X,F5.3,1X,F5.3)
*
* PRINT FOR SUBROUTINE BNPART
*
      PRINT 156
 156  FORMAT(*1DAILY PRINT FOR SUBROUTINE BNPART*)
      PRINT 49
 49   FORMAT(*- I  DAY COUNTER BPHSATE BCSTORE POOLCHK BCHODMD BCPOOL BT
     +RLCTE BFRDMD BLFDMD BRTDMD BSTDMD BRFRDMD BRLFDMD BRRTDMD BRSTDMD
     +BSUMDMD*)
      PRINT 50,(XI(I),XDAY(I),XCOUNTR(I),XBPHSAT(I),XBCSTOR(I),XPOOLCK(I
     +),XBCHODM(I),XBCPOOL(I),XBTRLCT(I),XBFRDMD(I),XBLFDMD(I),XBRTDMD(I
     +),XBSTDMD(I),XBRFRDM(I),XBRLFDM(I),XBRRTDM(I),XBRSTDM(I),XBSUMDM(I
     +),I=2,162,2)
 50   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F6.3,1X,F7.4,1X,F6.2,1X,F6.2,1X,F6.3,1X,F6.2,1X,F7.4,1X,
     +F7.4,1X,F7.4,1X,F7.4,1X,F7.3)
      PRINT 51
 51   FORMAT(*1 I  DAY COUNTER BFRINCR BLFINCR BRTINCR BSTINCR BDRYFR BD
     +RYLF BDRYRT BDRYST*)
      PRINT 52,(XI(I),XDAY(I),XCOUNTR(I),XBFRINC(I),XBLFINC(I),XBRTINC(I
     +),XBSTINC(I),XBDRYFR(I),XBDRYLF(I),XBDRYRT(I),XBDRYST(I),
     +I=2,162,2)
 52   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F6.2,1X,F6.2,1X,F6.2,1X,F6.2)
*
* PRINT FOR SUBROUTINE TOMPART
*
      PRINT 157
 157  FORMAT(*1DAILY PRINT FOR SUBROUTINE TOMPART*)
      PRINT 53
 53   FORMAT(*- I  DAY COUNTER TPHSATE TCSTORE POOLCHK TCHODMD TCPOOL TT
     +RLCTE TFRDMD TLFDMD TRTDMD TSTDMD TRFRDMD TRLFDMD TRRTDMD TRSTDMD
     +TSUMDMD*)
      PRINT 54,(XI(I),XDAY(I),XCOUNTR(I),XTPHSAT(I),XTCSTOR(I),XPOOLCH(I
     +),XTCHODM(I),XTCPOOL(I),XTTRLCT(I),XTFRDMD(I),XTLFDMD(I),XTRTDMD(I
     +),XTSTDMD(I),XTRFRDM(I),XTRLFDM(I),XTRRTDM(I),XTRSTDM(I),XTSUMDM(I
     +),I=2,162,2)
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 54   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F6.3,1X,F7.4,1X,F6.2,1X,F6.2,1X,F6.3,1X,F6.2,1X,F7.4,1X,
     +F7.4,1X,F7.4,1X,F7.4,1X,F7.3)
      PRINT 55
 55   FORMAT(*1 I  DAY COUNTER TFRINCR TLFINCR TRTINCR TSTINCR TDRYFR TD
     +RYLF TDRYRT TDRYST*)
      PRINT 56,(XI(I),XDAY(I),XCOUNTR(I),XTFRINC(I),XTLFINC(I),XTRTINC(I
     +),XTSTINC(I),XTDRYFR(I),XTDRYLF(I),XTDRYRT(I),XTDRYST(I),
     +I=2,162,2)
 56   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F7.4,1X,F6.2,1X,F6.2,1X,F6.2,1X,F6.2)
*
* PRINT FOR SUBROUTINE CANOPY
*
      PRINT 158
 158  FORMAT(*1DAILY PRINT FOR SUBROUTINE CANOPY*)
      PRINT 57
 57   FORMAT(*- I  DAY COUNTER MODE BNRADA BNRADB BGRAREA BDRYLF EBDRYLF
     + BLFAREA   BLAI BBOVLP BOVAREA BOVFRCT BNFLAG*)
      PRINT 58,(XI(I),XDAY(I),XCOUNTR(I),IMODE(I),XBNRADA(I),XBNRADB(I),
     +XBGRARA(I),XBDRYLF(I),XEBDRYL(I),XBLFARA(I),XBLAI(I),XBBOVLP(I),
     +XBOVARA(I),XBOVFRC(I),XBNFLAG(I),I=2,162,2)
 58   FORMAT(1X,I3,1X,I2,4X,I2,5X,I1,2X,F6.3,1X,F6.3,1X,F7.5,1X,
     +F6.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,F6.3,1X,F7.3,1X,F7.5,1X,F6.2)
      PRINT 59
 59   FORMAT(*1 I  TRAD TGRAREA TDRYLF TLFAREA TLAI TBOVLP*)
      PRINT 60,(XI(I),XTRAD(I),XTGRARA(I),XTDRYLF(I),XTLFARA(I),
     +XTLAI(I),XTBOVLP(I),I=2,162,2)
 60   FORMAT(1X,I3,F4.2,1X,F7.3,1X,F6.1,1X,F7.3,1X,F4.1,1X,F6.3)
*
* PRINT FOR SUBROUTINE YIELD
*
      PRINT 159
 159  FORMAT(*1DAILY PRINT FOR SUBROUTINE YIELD*)
      PRINT 61
 61   FORMAT(*- I  DAY COUNTER HTTDIST BBDIST HEXAREA HEXPHEC HEXCIRC TP
     +OPLTN BPOPHEX BPOPHEC TOTLPOP*)
      PRINT 62,(XI(I),XDAY(I),XCOUNTR(I),XHTTDIS(I),XBBDIST(I),
     +XHEXARE(I),XHEXPHE(I),XHEXCIR(I),XTPOPLT(I),XBPOPHX(I),XBPOPHC(I),
     +XTOTLPO(I),I=2,162,160)
 62   FORMAT(1X,I3,1X,I2,3X,I2,6X,F4.2,3X,F4.2,3X,F5.3,3X,
     +F6.0,1X,F7.2,1X,F7.0,1X,F7.0,1X,F7.0,1X,F7.0)
      PRINT 63
 63   FORMAT(*1 I  DAY COUNTER BFRFRT BYLDHEX BYLDM2 BYLDHEC TFRFRT TYLD
     +HEX TYLDM2 TYLDHEC SYLDHEX SYLDM2 SYLDHEC*)
      PRINT 64,(XI(I),XDAY(I),XCOUNTR(I),XBFRFRT(I),XBYLDHX(I),
     +XBYLDM2(I),XBYLDHC(I),XTFRFRT(I),XTYLDHX(I),XTYLDM2(I),
     +XTYLDHC(I),XSYLDHX(I),XSYLDM2(I),XSYLDHC(I),I=2,162,2)
 64   FORMAT(1X,I3,1X,I2,3X,I2,4X,F6.3,1X,F7.3,1X,F6.3,1X,F7.0,1X,
     +F6.3,1X,F7.3,1X,F6.3,1X,F7.0,1X,F7.3,1X,F6.3,1X,F7.0)
*
      GO TO 930
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
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*                       *                      *
*                       *  FINAL VALUES PRINT  *
*                       *                      *
*                       ************************
*
* THIS SECTION PRINTS FINAL VALUES ONLY FOR ALL VARIABLES REPRESENTED
* IN THE TWO PRECEDING PRINT SECTIONS.
*
* PRINT FOR SUBROUTINE PHOTO
*
 920  I=162
*
      PRINT 160
 160  FORMAT(*1FINAL VALUES PRINT FOR SUBROUTINE PHOTO*)
      PRINT 65
 65   FORMAT(*-DAY  I  COUNTER ENERGY TEMP RAIN RELHUM WINDSPD MONTH DAT
     +E JMONTH JDATE IMONTH IDATE          I  BNPLANT HARVEST*)
      PRINT 66,(XDAY(I),XI(I),XCOUNTR(I),XENERGY(I),XTEMP(I),XRAIN(I),
     +XRELHUM(I),XWINDSP(I),XMONTH(I),XDATE(I),XJMONTH(I),XJDATE(I),
     +XIMONTH(I),XIDATE(I),XI(I),XBNPLAN(I),XHARVES(I))
 66   FORMAT(I3,2X,I3,1X,I4,4X,F5.1,2X,F4.1,1X,F4.2,1X,F5.2,1X,F7.1,2X,
     +I4,2X,I3,4X,I4,1X,I4,2X,I4,3X,I4,3X,I8,4X,I2,6X,I2)
      PRINT 705
 705  FORMAT(*1  I  DAY CANDRES  DELTA  EVAPOTN  VOLS1    DVOL    DSWC
     +  SWC   RTDEPTH   SWPOT  LFWPOTL CUMIRGN CUMRAIN CUMEVAP  VAPSAT V
     +APTEMP*)
      PRINT 706,(XI(I),XDAY(I),XCANDRE(I),XDELTA(I),XEVAPOT(I),XVOLS1(I)
     +,XDVOL(I),XDSWC(I),XSWC(I),XRTDEPT(I),XSWPOT(I),XLFWPOT(I),
     +XCUMIRG(I),XCUMRAI(I),XCUMEVA(I),XVAPSAT(I),XVAPTEM(I))
 706  FORMAT(1X,I3,1X,I3,1X,F7.2,1X,F7.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,
     +F7.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,F7.2,1X,F7.2,1X,F7.2,1X,
     +F7.3,1X,F7.2)
      PRINT 67
 67   FORMAT(*1  I  DAY ENERGY AVENRGY   S1     S2     S3     S4     S5
     +    S6     S7   TLFRESP TPNRATE TPHSATE TCUMPHD*)
      PRINT 68,(XI(I),XDAY(I),XENERGY(I),XAVENGY(I),XS1(I),XS2(I),
     +XS3(I),XS4(I),XS5(I),XS6(I),XS7(I),XTLFRSP(I),XTPNRTE(I),
     +XTPHSTE(I),XTCUMPH(I))
 68   FORMAT(1X,I3,1X,I3,1X,F6.2,1X,F7.2,1X,F6.2,1X,F6.2,1X,F6.2,1X,
     +F6.2,1X,F6.2,1X,F6.2,1X,F6.2,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4)
      PRINT 69
 69   FORMAT(*1  I  DAY BLFRESP BPNRATE BPHSATE BCUMPHD BNHIGHT BNSHADE
     +TSHADE TGRSHDE STPNRTE TPNRTE SHADE TRESP BRESP*)
      PRINT 70,(XI(I),XDAY(I),XBLFRSP(I),XBPNRTE(I),XBPHSTE(I),
     +XBCUMPH(I),XBNHIGH(I),XBNSHDE(I),XTSHADE(I),XTGRSHD(I),
     +XSTPNRT(I),XTPNRTE(I),XSHADE(I),XTRESP(I),XBRESP(I))
 70   FORMAT(1X,I3,1X,I3,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,F7.3,1X,
     +F7.3,1X,F6.3,1X,F7.5,1X,F7.4,1X,F7.4,1X,F4.2,1X,F5.3,1X,F5.3)
*
* PRINT FOR SUBROUTINE BNPART
*
      PRINT 161
 161  FORMAT(*1FINAL VALUES PRINT FOR SUBROUTINE BNPART*)
      PRINT 71
 71   FORMAT(*- I  DAY COUNTER BPHSATE BCSTORE POOLCHK BCHODMD BCPOOL BT
     +RLCTE BFRDMD BLFDMD BRTDMD BSTDMD BRFRDMD BRLFDMD BRRTDMD BRSTDMD
     +BSUMDMD*)
      PRINT 72,(XI(I),XDAY(I),XCOUNTR(I),XBPHSAT(I),XBCSTOR(I),XPOOLCK(I
     +),XBCHODM(I),XBCPOOL(I),XBTRLCT(I),XBFRDMD(I),XBLFDMD(I),XBRTDMD(I
     +),XBSTDMD(I),XBRFRDM(I),XBRLFDM(I),XBRRTDM(I),XBRSTDM(I),XBSUMDM(I
     +))
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 72   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F6.3,1X,F7.4,1X,F6.2,1X,F6.2,1X,F6.3,1X,F6.2,1X,F7.4,1X,
     +F7.4,1X,F7.4,1X,F7.4,1X,F7.3)
      PRINT 73
 73   FORMAT(*- I  DAY COUNTER BFRINCR BLFINCR BRTINCR BSTINCR BDRYFR BD
     +RYLF BDRYRT BDRYST*)
      PRINT 74,(XI(I),XDAY(I),XCOUNTR(I),XBFRINC(I),XBLFINC(I),XBRTINC(I
     +),XBSTINC(I),XBDRYFR(I),XBDRYLF(I),XBDRYRT(I),XBDRYST(I))
 74   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F6.2,1X,F6.2,1X,F6.2,1X,F6.2)
*
* PRINT FOR SUBROUTINE TOMPART
*
      PRINT 162
 162  FORMAT(*1FINAL VALUES PRINT FOR SUBROUTINE TOMPART*)
      PRINT 75
 75   FORMAT(*- I  DAY COUNTER TPHSATE TCSTORE POOLCHK TCHODMD TCPOOL TT
     +RLCTE TFRDMD TLFDMD TRTDMD TSTDMD TRFRDMD TRLFDMD TRRTDMD TRSTDMD
     +TSUMDMD*)
      PRINT 76,(XI(I),XDAY(I),XCOUNTR(I),XTPHSAT(I),XTCSTOR(I),XPOOLCH(I
     +),XTCHODM(I),XTCPOOL(I),XTTRLCT(I),XTFRDMD(I),XTLFDMD(I),XTRTDMD(I
     +),XTSTDMD(I),XTRFRDM(I),XTRLFDM(I),XTRRTDM(I),XTRSTDM(I),XTSUMDM(I
     +))
 76   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F6.3,1X,F7.4,1X,F6.2,1X,F6.2,1X,F6.3,1X,F6.2,1X,F7.4,1X,
     +F7.4,1X,F7.4,1X,F7.4,1X,F7.3)
      PRINT 77
 77   FORMAT(*- I  DAY COUNTER TFRINCR TLFINCR TRTINCR TSTINCR TDRYFR TD
     +RYLF TDRYRT TDRYST*)
      PRINT 78,(XI(I),XDAY(I),XCOUNTR(I),XTFRINC(I),XTLFINC(I),XTRTINC(I
     +),XTSTINC(I),XTDRYFR(I),XTDRYLF(I),XTDRYRT(I),XTDRYST(I))
 78   FORMAT(1X,I3,1X,I2,3X,I2,4X,F7.4,1X,F7.4,1X,F7.4,1X,
     +F7.4,1X,F6.2,1X,F6.2,1X,F6.2,1X,F6.2)
*
* PRINT FOR SUBROUTINE CANOPY
*
 163  FORMAT(*1FINAL VALUES PRINT FOR SUBROUTINE CANOPY*)
      PRINT 163
      PRINT 79
 79   FORMAT(*- I  DAY COUNTER MODE BNRADA BNRADB BGRAREA BDRYLF EBDRYLF
     + BLFAREA   BLAI BBOVLP BCVAREA BOVFRCT BNFLAG*)
      PRINT 80,(XI(I),XDAY(I),XCOUNTR(I),IMODE(I),XBNRADA(I),XBNRADB(I),
     +XBGRARA(I),XBDRYLF(I),XEBDRYL(I),XBLFARA(I),XBLAI(I),XBBOVLP(I),
     +XBOVARA(I),XBOVFRC(I),XBNFLAG(I))
 80   FORMAT(1X,I3,1X,I2,4X,I2,5X,I1,2X,F6.3,1X,F6.3,1X,F7.5,1X,
     +F6.3,1X,F7.3,1X,F7.3,1X,F7.3,1X,F6.3,1X,F7.3,1X,F7.5,1X,F6.2)
      PRINT 81
 81   FORMAT(*- I  TRAD TGRAREA TDRYLF TLFAREA TLAI TBOVLP*)
      PRINT 82,(XI(I),XTRAD(I),XTGRARA(I),XTDRYLF(I),XTLFARA(I),
     +XTLAI(I),XTBOVLP(I))
 82   FORMAT(1X,I3,F4.2,1X,F7.3,1X,F6.1,1X,F7.3,1X,F4.1,1X,F6.3)
*
* PRINT FOR SUBROUTINE YIELD
*
      PRINT 164
 164  FORMAT(*1FINAL VALUES PRINT FOR SUBROUTINE YIELD*)
      PRINT 83
 83   FORMAT(*- I  DAY COUNTER HTTDIST BBDIST HEXAREA HEXPHEC HEXCIRC TP
     +OPLTN BPOPHEX BPOPHEC TOTLPOP*)
      PRINT 84,(XI(I),XDAY(I),XCOUNTR(I),XHTTDIS(I),XBBDIST(I),
     +XHEXARE(I),XHEXPHE(I),XHEXCIR(I),XTPOPLT(I),XBPOPHX(I),XBPOPHC(I),
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     +XTOTLPO(I))
 84   FORMAT(1X,I3,1X,I2,3X,I2,6X,F4.2,3X,F4.2,3X,F5.3,3X,
     +F6.0,1X,F7.2,1X,F7.0,1X,F7.0,1X,F7.0,1X,F7.0)
      PRINT 85
 85   FORMAT(*- I  DAY COUNTER BFRFRT BYLDHEX BYLDM2 BYLDHEC TFRFRT TYLD
     +HEX TYLDM2 TYLDHEC SYLDHEX SYLDM2 SYLDHEC*)
      PRINT 86,(XI(I),XDAY(I),XCOUNTR(I),XBFRFRT(I),XBYLDHX(I),
     +XBYLDM2(I),XBYLDHC(I),XTFRFRT(I),XTYLDHX(I),XTYLDM2(I),
     +XTYLDHC(I),XSYLDHX(I),XSYLDM2(I),XSYLDHC(I))
 86   FORMAT(1X,I3,1X,I2,3X,I2,4X,F6.3,1X,F7.3,1X,F6.3,1X,F7.0,1X,
     +F6.3,1X,F7.3,1X,F6.3,1X,F7.0,1X,F7.3,1X,F6.3,1X,F7.0)
*
      GO TO 930
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
*
*                           *****************
*                           *               *
*                           *  YIELD PRINT  *
*                           *               *
*                           *****************
*
* THIS SECTION PRINTS FINAL VALUES ONLY FOR THOSE VARIABLES PERTINENT TO
* YIELD. THIS INCLUDES SUCH VARIABLES AS THOSE FOR DAY, HEXAGON SIZE,
* HEXAGON NUMBER, ETC.
*
 925  I=162
*
      PRINT 87
 87   FORMAT(*-DAY  I  COUNTER ENERGY TEMP RAIN RELHUM WINDSPD MONTH DAT
     +E JMONTH JDATE IMONTH IDATE         I  BNPLANT HARVEST*)
      PRINT 88,(XDAY(I),XI(I),XCOUNTR(I),XENERGY(I),XTEMP(I),XRAIN(I),
     +XRELHUM(I),XWINDSP(I),XMONTH(I),XDATE(I),XJMONTH(I),XJDATE(I),
     +XIMONTH(I),XIDATE(I),XI(I),XBNPLAN(I),XHARVES(I))
 88   FORMAT(I3,2X,I3,1X,I4,4X,F5.1,2X,F4.1,1X,F4.2,1X,F5.2,1X,F6.2,3X,
     +I4,2X,I3,4X,I4,1X,I4,2X,I4,3X,I4,3X,I8,4X,I2,6X,I2)
      PRINT 89
 89   FORMAT(*- I  DAY COUNTER HTTDIST BBDIST HEXAREA HEXPHEC HEXCIRC TP
     +OPLTN BPOPHEX BPOPHEC TOTLPOP*)
      PRINT 90,(XI(I),XDAY(I),XCOUNTR(I),XHTTDIS(I),XBBDIST(I),
     +XHEXARE(I),XHEXPHE(I),XHEXCIR(I),XTPOPLT(I),XBPOPHX(I),XBPOPHC(I),
     +XTOTLPO(I))
 90   FORMAT(1X,I3,1X,I2,3X,I2,6X,F4.2,3X,F4.2,3X,F5.3,3X,
     +F6.0,1X,F7.2,1X,F7.0,1X,F7.0,1X,F7.0,1X,F7.0)
      PRINT 91
 91   FORMAT(*- I  DAY COUNTER BFRFRT BYLDHEX BYLDM2 BYLDHEC TFRFRT TYLD
     +HEX TYLDM2 TYLDHEC SYLDHEX SYLDM2 SYLDHEC*)
      PRINT 92,(XI(I),XDAY(I),XCOUNTR(I),XBFRFRT(I),XBYLDHX(I),
     +XBYLDM2(I),XBYLDHC(I),XTFRFRT(I),XTYLDHX(I),XTYLDM2(I),
     +XTYLDHC(I),XSYLDHX(I),XSYLDM2(I),XSYLDHC(I))
 92   FORMAT(1X,I3,1X,I2,3X,I2,4X,F6.3,1X,F7.3,1X,F6.3,1X,F7.0,1X,
     +F6.3,1X,F7.3,1X,F6.3,1X,F7.0,1X,F7.3,1X,F6.3,1X,F7.0)
*
 930  CONTINUE
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
*
*
      PRINT 939
 939  FORMAT(*0*,************************************************************
     +*******************)
      ENDFILE 61
      CALL CONNEC (6LOUTPUT)
      PRINT 940
 940  FORMAT(*0*,5X,*DO YOU WANT TO RUN AGAIN, YES OR NO?*)
      READ 941, E
 941  FORMAT(A2)
      IF(E.EQ.2HYE) GO TO 1000
*
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*
      END
*
*
**********************************************************************
*                                                                    *
*                                                                    *
*                    ************************
*                    *                      *
*                    *  SUBROUTINE WEATHER  *
*                    *                      *
*                    ************************
*
      SUBROUTINE WEATHER
*
**********************************************************************
*                                                                    *
*              DEFINITION OF CONSTANTS AND VARIABLES                 *
*                                                                    *
* COUNTER = COUNT OF NUMBER OF ITERATIONS DURING A PARTICULAR DAY    *
* DAY     = DAYS AFTER COMMENCEMENT OF THE SIMULATION (FIRST DAY     *
*           IS DEFINED AS DAY 1)    DAY                              *
* ENERGY  = LIGHT FLUX DENSITY INCIDENT AT TOP OF CANOPY    W M**-2  *
* IDAY    = VARIANT OF DAY                                           *
* IMONTH  = VARIANT OF MONTH                                         *
* JDAY    = VARIANT OF DAY                                           *
* JMONTH  = VARIANT OF MONTH                                         *
* MONTH   = MONTH OF THE YEAR                                        *
* RAIN    = PRECIPITATION  M                                         *
* RELHUM  = RELATIVE HUMIDITY                                        *
* TEMP    = DRY BULB TEMPERATURE    C                                *
* WINDSPD = WIND SPEED    M S**-1                                    *
*                                                                    *
**********************************************************************
*
* ESTABLISH REAL AND INTEGER VARIABLES
*
      INTEGER COUNTER,DAY,PRINTYP,XCCUNTR,XDAY,XI,XMONTH,XDATE,XJMONTH,
     +XJDATE,XIMONTH,XIDATE,DATE,BNPLANT,HARVEST,XBNPLAN,XHARVES
      REAL MBNRADB,LFWPOTL
*
* ESTABLISH COMMON BLOCKS
*
      COMMON /MAIN/ BBDIST,BDRYFR,BDRYLF,BDRYRT,BDRYST,BGRAREA,BLAI,
     +BNRADA,BNRADB,BPHSATE,COUNTER,ENERGY(24),HTTDIST,RAIN,
     +RELHUM(24),TDRYFR,TDRYLF,TDRYRT,TDRYST,TEMP(24),TGRAREA,TLAI,
     +TPHSATE,TRAD,TTDIST,WINDSPD(24),I,SHADE(101,8),IHR,DAY,LFWPOTL,
```

```
     +HBBDIST,MONTH,DATE,IMONTH,IDATE,JMONTH,JDATE,BNPLANT,HARVEST
*
*
* READ TEMPERATURE, WINDSPEED AND RELATIVE HUMIDITY DATA FROM NATIONAL
* WEATHER SERVICE FILE EXTRACTS ON PERMANENT FILE. THE FOLLOWING DO
* LOOPS POSITION THE START OF THE READ AT THE CORRECT DATE.
*
 555  READ(10,100)MONTH,DATE,(TEMP(J),WINDSPD(J),RELHUM(J),J=1,24)
 100  FORMAT(16X,I2,1X,I2,20X,F2.0,1X,F2.0,1X,F3.0,23(6X,F2.0,1X,F2.0,1X
     +,F3.0))
      IF(MONTH.LT.6) GO TO 555
      IF(MONTH.GT.6) GO TO 333
      IF(DATE.LT.23) GO TO 555
*
* READ PRECIPITATION DATA FROM A PERMANENT FILE.
*
 333  READ(30,300)JMONTH,JDATE,RAIN
 300  FORMAT(I2,I2,F4.2)
      IF(JMONTH.LT.6) GO TO 333
      IF(JMONTH.GT.6) GO TO 777
      IF(JDATE.LT.23) GO TO 333
*
* READ ENERGY DATA FROM A PERMANENT FILE.
*
 777  READ(20,200)IMONTH,IDATE,(ENERGY(K),K=1,24)
 200  FORMAT(6X,2I2,24F4.1)
      IF(IMONTH.LT.6) GO TO 777
      IF(IMONTH.GT.6) GO TO 888
      IF(IDATE.LT.23) GO TO 777
 888  CONTINUE
*
      RETURN
      END
*                                                                      *
*                                                                      *
************************************************************************
*
*
*
************************************************************************
*                                                                      *
*                                                                      *
*                     **********************
*                     *                    *
*                     *  SUBROUTINE WATER  *
*                     *                    *
*                     **********************
*
      SUBROUTINE WATER
*
************************************************************************
*                                                                      *
*                DEFINITION OF CONSTANTS AND VARIABLES                 *
*                                                                      *
* BLAI    = BEAN LEAF AREA INDEX                                       *
* BNRADB  = BEAN RADIUS IN THE DIRECTION PERPENDICULAR TO THE ROW   M  *
* ATMDRES = ATMOSPHERIC DIFFUSION RESISTANCE   S CM**-1                *
* CANDRES = CANOPY DIFFUSION RESISTANCE   S CM**-1                     *
* CUMEVAP = CUMULATIVE EVAPOTRANSPIRATION   M                          *
* CUMIRGN = CUMULATIVE IRRIGATION   M                                  *
* CUMRAIN = CUMULATIVE PRECIPITATION   M                               *
```

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* CELTA    = CHANGE OF SATURATION VAPOR PRESSURE WITH TEMPERATURE   MB  *
* DSWC     = CHANGE IN SOIL MOISTURE IN A GIVEN VOLUME OF SOIL          *
*                                                         M HR**-1      *
* DVOL     = CHANGE IN SOIL VOLUME OCCUPIED BY THE ROOT SYSTEM   M**3   *
* ENERGY   = LIGHT FLUX DENSITY INCIDENT AT TOP OF CANOPY   W M**-2     *
* EVAPOTN  = ACTUAL EVAPOTRANSPIRATION RATE   M HR**-1                  *
* GAMMA    = CONSTANT   MB                                              *
* IRRIGTN  = IRRIGATION   M                                             *
* LFWPOTL  = LEAF WATER POTENTIAL   BAR                                 *
* PAR      = PHOTOSYNTHETICALLY ACTIVE RADIATION INCIDENT AT TOP OF     *
*            CANOPY   ERG CM**-2 S**-1                                  *
* RTDEPTH  = ROOT SYSTEM DEPTH   M                                      *
* RAIN     = PRECIPITATION  M                                           *
* RELHUM   = RELATIVE HUMIDITY                                          *
* RHMSAVE  = STORED VALUE OF RELHUM TO ALLOW FOR MISSING VALUES IN      *
*            THE WEATHER DATA                                           *
* SOILBD   = SOIL BULK DENSITY   G CM**-3                               *
* SWC      = VOLUMETRIC SOIL WATER CONTENT                              *
* SWPOT    = SOIL WATER POTENTIAL   BAR                                 *
* TEMP     = DRY BULB TEMPERATURE   C                                   *
* TMPSAVE  = STORED VALUE OF TEMP TO ALLOW FOR MISSING VALUES IN THE    *
*            WEATHER DATA                                               *
* VAPSAT   = SATURATED VAPOR PRESSURE AT CURRENT TEMPERATURE   BAR      *
* VAPTEMP  = VAPOR PRESSURE AT CURRENT TEMPERATURE   BAR                *
* VOLS1    = SOIL VOLUME OCCUPIED BY ROOT SYSTEM   M**3                 *
* VOLS2    = NEW VALUE OF VOLS1                                         *
* WINDCON  = CONSTANT                                                   *
* WINDSPD  = WIND SPEED    M S**-1                                      *
* WNDSAVE  = STORED VALUE OF WINDSPD TO ALLOW FOR MISSING VALUES IN     *
*            THE WEATHER DATA                                           *
*                                                                       *
*************************************************************************
*
* ESTABLISH REAL AND INTEGER VARIABLES
*
      INTEGER COUNTER,DAY,PRINTYP,XCOUNTR,XDAY,XI,XMONTH,XDATE,XJMONTH,
     +XJDATE,XIMONTH,XIDATE,DATE,BNPLANT,HARVEST,XBNPLAN,XHARVES
      REAL MBNRADB,LFWPOTL
*
* ESTABLISH COMMON BLOCKS
*
      COMMON /MAIN/ BBDIST,BDRYFR,BDRYLF,BDRYRT,BDRYST,BGRAREA,BLAI,
     +BNRADA,BNRADB,BPHSATE,COUNTER,ENERGY(24),HTTDIST,RAIN,
     +RELHUM(24),TDRYFR,TDRYLF,TDRYRT,TDRYST,TEMP(24),TGRAREA,TLAI,
     +TPHSATE,TRAD,TTDIST,WINDSPD(24),I,SHADE(101,8),IHR,DAY,LFWPOTL,
     +HBBDIST,MONTH,DATE,IMONTH,IDATE,JMONTH,JDATE,BNPLANT,HARVEST
*
      COMMON /WATER/XCANDRE(180),XCUMEVA(180),XCUMIRG(180),XCUMRAI(180),
     +XDELTA(180),XDSWC(180),XDVOL(180),XEVAPOT(180),XLFWPOT(180),
     +XRTDEPT(180),XSWC(180),XSWPOT(180),XVOLS1(180),XVAPSAT(180),
     +XVAPTEM(180)
*
* INITIALIZE CONSTANTS AND VARIABLES
*
      IF(I.GT.0.OR.COUNTER.GT.1) GO TO 10
*
      BLAI=1.
      BNRADB=.05
      CUMEVAP=0.
      CUMIRGN=0.
      CUMRAIN=0.
```

```
      GAMMA=.66
      IRRIGTN=0.
      RHMSAVE=50.
      RTDEPTH=.3
      SOILBD=1.25
      SWC=.15
      TLAI=BLAI
      TMPSAVE=20.
      TRAD=.1
      VOLS2=1.047*(BNRADB**2.)*RTDEPTH
      VOLS1=VOLS2
      WINDCON=82.8
      WNDSAVE=360.
*
 10   CONTINUE
*
*                         *******************
*                         *                 *
*                         *  WEATHER INPUT  *
*                         *   ADJUSTMENTS   *
*                         *                 *
*                         *******************
*
* CONVERT WEATHER VARIABLES TO CORRECT UNITS AND PROTECT AGAINST
* MISSING DATA
*
* ENERGY IS CONVERTED FROM LANGLEY (CAL CM**-2) RECEIVED IN 1 HR, TO
* W M**-2.
*
      PAR=ENERGY(IHR)/120.
      ENERGY(IHR)=ENERGY(IHR)*11.625
*
* RAIN CONVERTED FROM INCHES TO M
*
      RAIN=RAIN*.0254
      IF(COUNTER.GT.1) RAIN=0.
*
* TEMPERATURE CONVERTED FROM FARENHEIT TO CENTIGRADE
*
      TEMP(IHR)=(TEMP(IHR)-32.)*.55556
*
* WINDSPEED CONVERTED FROM KNOTS TO M HR**-1
*
      WINDSPD(IHR)=WINDSPD(IHR)*.5148
*
* STORE WEATHER VARIABLE VALUES TO PROTECT AGAINST GAPS IN THE RECORD.
*
      IF(RELHUM(IHR).LT..0001) RELHUM(IHR)=RHMSAVE
      RHMSAVE=RELHUM(IHR)
      IF(TEMP(IHR).LT..0001) TEMP(IHR)=TMPSAVE
      TMPSAVE=TEMP(IHR)
      IF(WINDSPD(IHR).LT..0001) WINDSPD(IHR)=WNDSAVE
      WNDSAVE=WINDSPD(IHR)
*
*
*                      ************************
*                      *                      *
*                      *  EVAPOTRANSPIRATION  *
*                      *                      *
*                      ************************
*
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```
* THE EVAPOTRANSPIRATION, SOIL WATER AND LEAF WATER POTENTIAL SECTIONS
* OF THIS SUBROUTINE ARE ADAPTED FROM SUBROUTINE WATER IN SOYMOD/OARDC,
* PUBLISHED BY G. E. MEYER, R. B. CURRY, J. G. STREETER AND
* H. J. MEDERSKI, OHIO AGRICULTURAL RESEARCH AND DEVELOPMENT CENTER,
* RESEARCH BULLETIN 1113, DECEMBER 1979. THE ACTIVE ASSISTANCE
* RECEIVED FROM DR. BRUCE CURRY IN PROVIDING AND EXPLAINING THE CODE
* IS GRATEFULLY ACKNOWLEDGED. MODIFICATIONS HAVE BEEN MADE TO ADAPT
* THE LOGIC TO THE REQUIREMENTS AND INPUTS OF MULTICROP. HOWEVER, THE
* SECTION REMAINS ESSENTIALLY THE SAME AS SOYMOD/OARDC.
*
* COMPUTE ATMOSPHERIC AND CANOPY DIFFUSION RESISTANCES
*
* ATMOSPHERIC DIFFUSION RESISTANCE FUNCTION IS AFTER C. T. DE WIT,
* AGR. RES. REP. #663, CENTER FOR AGRICULTURAL PUBLICATIONS AND
* DOCUMENTATION, WAGENINGEN, 1965.
*
      ATMDRES=8.28/WINDSPD(IHR)
      IF(ENERGY(IHR).LT..001) GO TO 100
*
* STOMATAL DIFFUSION RESISTANCE FUNCTION IS FROM DATA BY
* P. E. RIJTEMA, AGR. RES. REP. #659, CENTER FOR AGRICULTURAL
* PUBLICATIONS AND DOCUMENTATION, WAGENINGEN, 1965.
*
      STOMRES=34.5 - 17.2*ALOG10(ENERGY(IHR))
      IF(STOMRES.LT.2.) STOMRES=2.
      GO TO 110
 100  STOMRES=34.5
 110  CONTINUE
*
* STOMRES - LAI RELATIONSHIP IS AFTER  T. A. BLACK,  C. B. TANNER, AND
* W. R. GARDNER,  AGRONOMY J. 62:66-69, 1970.
      CANDRES=STOMRES/(2.*BLAI)
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) CANDRES=STOMRES/(2.*TLAI)
      IF(CANDRES.LT.2.) CANDRES=2.
      CANDRES=CANDRES/36.
*
* COMPUTE SATURATION VAPOR PRESSURE AT THE CURRENT TEMPERATURE. COMPUTE
* ACTUAL VAPOR PRESSURE AT THE CURRENT TEMPERATURE GIVEN RELATIVE
* HUMIDITY.
*
      VAPSAT=EXP(1.806 + .0712*TEMP(IHR) - .0002298*TEMP(IHR)**2.)
      VAPTEMP=RELHUM(IHR)*VAPSAT/100.
*
* COMPUTE EVAPOTRANSPIRATION USING A MODIFIED PENMAN EQUATION AFTER
* J. L. MONTEITH, SOC. EXPER. BIOL. 19 (205-234), 1965.
*
      DELTA=(.0712 - .0004596*TEMP(IHR))*VAPSAT
      PART1=DELTA + GAMMA*(1. + CANDRES/ATMDRES)
      PART2=DELTA*1.5*PAR + 290.*(VAPSAT - VAPTEMP)/ATMDRES
      EVAPOTN=(PART2*1.E-6)/(PART1*585.)
      IF(EVAPOTN.LT.0.) EVAPOTN=0.
*
*                         **************************
*                         *                        *
*                         *       SOIL WATER       *
*                         *          AND           *
*                         *  LEAF WATER POTENTIAL  *
*                         *                        *
*                         **************************
*
* COMPUTE CHANGE IN SOIL WATER CONTENT
```

```
*
      DSWC=(3.1416*BNRADB**2.)*1.E-4*(RAIN + IRRIGTN - EVAPOTN)
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) DSWC=(3.1416*TRAD**2.)
     **1.E-4*(RAIN + IRRIGTN - EVAPOTN)
      SWC=SWC + DSWC/VOLS1
*
* ADJUST SOIL VOLUME OCCUPIED BY THE ROOTS AND PLACE LIMITS ON SOIL
* WATER CONTENT
*
      VOLS2=1.047*(BNRADB**2.)*RTDEPTH
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST)VOLS2=1.047*(TRAD**2.)*RTDEPTH
      DVOL=VOLS2-VOLS1
      SWC=(.15*DVOL + SWC*VOLS1)/VOLS2
      VOLS1=VOLS2
      IF(SWC.GT..3) SWC=.3
      IF(SWC.LT..1) SWC=.1
*
* INCREMENT CUMULATIVE VALUES FOR EVAPOTRANSPIRATION, IRRIGATION
* AND RAIN
*
      CUMEVAP=CUMEVAP + EVAPOTN
      CUMIRGN=CUMIRGN + IRRIGTN
      CUMRAIN=CUMRAIN + RAIN
*
* COMPUTE SOIL WATER POTENTIAL FROM SOIL WATER CONTENT AND BULK
* DENSITY. FUNCTION IS FOR WOOSTER SILT LOAM, AND IS DERIVED FROM DATA
* BY R. A. BRADY, F. M. GOLTZ, W. L. POWERS AND E. T. KANEMASU,
* AGRON. J. 69 (97-99), 1977.
*
      SWPOT=42.61*EXP(-15.27*SWC/SOILBD)
*
* COMPUTE LEAF WATER POTENTIAL FROM SOIL WATER POTENTIAL. FUNCTION IS
* FOR SOYBEAN, AND COMES FROM BRADY ET AL, AS ABOVE.
*
      LFWPOTL=2.61*EXP(.161*SWPOT)
*
*
* PLACE VARIABLE VALUES INTO ARRAYS FOR LATER PRINTING. ALL VARIABLE
* NAMES STARTING WITH X ARE USED FOR PRINTING ONLY.
*
      IF(COUNTER.NE.12.AND.COUNTER.NE.24) GO TO 999
*
      XCANDRE(I)=CANDRES
      XCUMEVA(I)=CUMEVAP
      XCUMIRG(I)=CUMIRGN
      XCUMRAI(I)=CUMRAIN
      XDELTA(I)=DELTA
      XDSWC(I)=DSWC
      XDVOL(I)=DVOL
      XEVAPOT(I)=EVAPOTN
      XLFWPOT(I)=LFWPOTL
      XRTDEPT(I)=RTDEPTH
      XSWC(I)=SWC
      XSWPOT(I)=SWPOT
      XVAPSAT(I)=VAPSAT
      XVAPTEM(I)=VAPTEMP
      XVOLS1(I)=VOLS1
*
 999  CONTINUE
*
      RETURN
```

```
      END
*                                                                       *
*                                                                       *
*************************************************************************
*
*
*
*************************************************************************
*                                                                       *
*                                                                       *
*                      *********************
*                      *                   *
*                      *  SUBROUTINE PHOTO *
*                      *                   *
*                      *********************
*
      SUBROUTINE PHOTO
*
*************************************************************************
*                                                                       *
*                 DEFINITION OF CONSTANTS AND VARIABLES                 *
*                                                                       *
* AVENRGY = AVERAGE LIGHT FLUX DENSITY INCIDENT AT TOP OF CANOPY        *
*           DURING PREVIOUS WEEK                   W M**-2              *
* BA      = CONSTANT                                                    *
* BB      = CONSTANT                                                    *
* BCUMPHD = BEAN CUMULATIVE PHOTOSYNTHESIS PER DAY   MG CO2             *
* BEXCOEF = BEAN CANOPY EXTINCTION COEFFICIENT                          *
* BGRAREA = AREA UNDER THE BEAN CANOPY   M**2                           *
* BLAI    = BEAN LEAF AREA INDEX                                        *
* BLFRESP = BEAN LEAF DARK RESPIRATION RATE PER UNIT GROUND AREA        *
*                                             MG CO2 M**-2 S**-1        *
* BNHIGHT = HEIGHT OF THE BEAN CANOPY   M                               *
* BNPLANT = BEAN PLANTING DATE IN MODEL DAYS                            *
* BNRADB  = BEAN RADIUS IN THE DIRECTION PERPENDICULAR TO THE ROW   M   *
* BNSHADE = HORIZONTAL LENGTH OF THE BEAN CANOPY SHADOW   M             *
* BPHSATE = BEAN NET PHOTOSYNTHATE EXPRESSED AS GLUCOSE   G             *
* BPNRATE = BEAN NET PHOTOSYNTHESIS RATE PER UNIT GROUND AREA           *
*                                             MG CO2 M**-2 S**-1        *
* BRESP   = BEAN TOTAL DARK RESPIRATION RATE PER UNIT GROUND AREA       *
*                                             MG CO2 M**-2 S**-1        *
* BSTRESP = BEAN STRUCTURE DARK RESPIRATION RATE PER UNIT GROUND        *
*           AREA (ROOT, STEM AND FRUIT)       MG CO2 M**-2 S**-1        *
* BTRANS  = BEAN LEAF TRANSMISSION COEFFICIENT                          *
* BUTILIZ = BEAN LEAF LIGHT UTILIZATION EFFICIENCY   MG CO2 J**-1       *
* BX      = CONSTANT                                                    *
* BY      = CONSTANT                                                    *
* COUNTER = COUNT OF NUMBER OF ITERATIONS DURING A PARTICULAR DAY       *
* CO2     = CO2 CONCENTRATION   MG CO2 M**-3                            *
* CUMENDY = CUMULATIVE ENERGY OVER THE DAY   W M**-2                    *
* DAY     = DAYS AFTER COMMENCEMENT OF THE SIMULATION (FIRST DAY        *
*           IS DEFINED AS DAY 1)   DAY                                  *
* ECOUNT  = COUNT OF EVENT WHEN ENERGY EXCEEDS .01 , SET TO ZERO        *
*           EACH DAY WHEN COUNTER = U. USED TO COMPUTE S1 IN PHOTO.     *
* ENERGY  = LIGHT FLUX DENSITY INCIDENT AT TOP OF CANOPY   W M**-2      *
* ENSTORE = STORED VALUE OF ENERGY FOR THAT ITERATION   W M**-2         *
* HARVEST = BEAN HARVEST DATE IN MODEL DAYS                             *
* HTTDIST = HALF THE TOMATO-TOMATO PLANTING DISTANCE   M                *
* IHR     = SAME AS COUNTER.                                            *
* KOUNTER = SPECIAL VERSION OF COUNTER WHICH RUNS FROM 1 TO 8 AND IS    *
*           USED IN CALLING SHADE                                       *
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* RATIOE   = LESSER VALUE OF RATIOP AND RATIOT, USED TO SCALE DOWN       *
*            PHOTOSYNTHETIC RATE                                         *
* RATIOM   = ADJUSTMENT TO TOMATO PHOTOSYNTHETIC RATE DUE TO AGE OF      *
*            THE CANOPY                                                  *
* RATIOP   = ADJUSTMENT TO PHOTOSYNTHETIC RATE DUE TO LEAF WATER         *
*            POTENTIAL DIFFERENCES FROM THE OPTIMUM                      *
* RATIOT   = ADJUSTMENT TO PHOTOSYNTHETIC RATE DUE TO TEMPERATURE        *
*            DIFFERENCES FROM THE OPTIMUM                                *
* S        = AVERAGE ENERGY RECEIVED DURING A 3 HOUR PERIOD FOR ONE      *
*            OF THE PREVIOUS 7 DAYS                                      *
* SHADE    = RATIO OF AN OBJECT"S SHADOW LENGTH TO THE HEIGHT OF         *
*            THE OBJECT                                                  *
* STPNRTE = SHADED TOMATO NET PHOTOSYNTHESIS RATE PER UNIT GROUND        *
*            AREA    MG CO2 M**-2 S**-1                                  *
* TA       = CONSTANT                                                    *
* TB       = CONSTANT                                                    *
* TCUMPHD = TOMATO CUMULATIVE PHOTOSYNTHESIS PER DAY   MG CO2            *
* TDAY     = CONVERSION OF DAY TO REAL FOR RATIOM CALCULATION            *
* TDIAM    = TOMATO CANOPY DIAMETER   M                                  *
* TEMP     = DRY BULB TEMPERATURE   C                                    *
* TEXCOEF = TOMATO CANOPY EXTINCTION COEFFICIENT                         *
* TGRAREA = AREA UNDER THE TOMATO CANOPY   M**2                          *
* TGRSHDE = GROUND AREA OF THE TOMATO CANOPY SHADED BY THE               *
*            BEAN CANOPY   M**2                                          *
* TLAI     = TOMATO LEAF AREA INDEX                                      *
* TLFRESP = TOMATO LEAF DARK RESPIRATION RATE PER UNIT GROUND AREA       *
*                                              MG CO2 M**-2 S**-1        *
* TPHSATE = TOMATO NET PHOTOSYNTHATE EXPRESSED AS GLUCOSE   G            *
* TPNRATE = TOMATO NET PHOTOSYNTHESIS RATE PER UNIT GROUND AREA          *
*                                              MG CO2 M**-2 S**-1        *
* TRAD     = TOMATO CANOPY RADIUS   M                                    *
* TRESP    = TOMATO TOTAL DARK RESPIRATION RATE PER UNIT GROUND AREA     *
*                                              MG CO2 M**-2 S**-1        *
* TSHADE   = HORIZONTAL ENCROACHMENT DISTANCE OF THE BEAN SHADOW         *
*            ONTO THE TOMATO GROUND AREA   M                             *
* TSTRESP = TOMATO STRUCTURE DARK RESPIRATION RATE PER UNIT GROUND       *
*            AREA (ROOT, STEM AND FRUIT)       MG CO2 M**-2 S**-1        *
* TTRANS   = TOMATO LEAF TRANSMISSION COEFFICIENT                        *
* TUTILIZ = TOMATO LEAF LIGHT UTILIZATION EFFICIENCY   MG CO2 J**-1      *
* TX       = CONSTANT                                                    *
* TY       = CONSTANT                                                    *
*                                                                        *
**************************************************************************
*
* ESTABLISH REAL AND INTEGER VARIABLES
*
      INTEGER COUNTER,DAY,PRINTYP,XCOUNTR,XDAY,XI,XMONTH,XDATE,XJMONTH,
     +XJDATE,XIMONTH,XIDATE,DATE,BNPLANT,HARVEST,XBNPLAN,XHARVES
      REAL MBNRADB,LFWPOTL
*
* ESTABLISH COMMON BLOCKS
*
      COMMON /MAIN/ BBDIST,BDRYFR,BDRYLF,BDRYRT,BDRYST,BGRAREA,BLAI,
     +BNRADA,BNRADB,BPHSATE,COUNTER,ENERGY(24),HTTDIST,RAIN,
     +RELHUM(24),TDRYFR,TDRYLF,TDRYRT,TDRYST,TEMP(24),TGRAREA,TLAI,
     +TPHSATE,TRAD,TTDIST,WINDSPD(24),I,SHADE(101,8),IHR,DAY,LFWPOTL,
     +HBBDIST,MONTH,DATE,IMONTH,IDATE,JMONTH,JDATE,BNPLANT,HARVEST
*
      COMMON /PHOTO/XDAY(180),XSHADE(180),XCOUNTR(180),XAVENGY(180),
     +XBCUMPH(180),XBLFRSP(180),XBNHIGH(180),XBNSHDE(180),XBPHSTE(180),
     +XBPNRTE(180),XBRESP(180),XENERGY(180),XS1(180),XS2(180),XS3(180),
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     +XS4(180),XS5(180),XS6(180),XS7(180),XSTPNRT(180),XTCUMPH(180),
     +XTGRSHD(180),XTLFRSP(180),XTPHSTE(180),XTPNRTE(180),XTRESP(180),
     +XTSHADE(180),XRAIN(180),XRELHUM(180),XTEMP(180),XWINDSP(180),
     +XI(180),XMONTH(180),XDATE(180),XJMONTH(180),XJDATE(180),
     +XIMONTH(180),XIDATE(180),XBNPLAN(180),XHARVES(180)
*
* INITIALIZE CONSTANTS AND VARIABLES
*
      IF(I.GT.0.OR.COUNTER.GT.1) GO TO 10
*
      AVENRGY=322.
      BA=8.5E-5
      BB=2.1E-2
      BEXCOEF=.6
      BGRAREA=.015
      BLAI=1.
      BNHIGHT=.07
      BNRADB=.05
      BNSHADE=0.
      BTRANS=.12
      BUTILIZ=11.5E-3
      BX=2.4E-3
      BY=1.9E-2
      CO2=730.
      S1=242.
      S2=389.
      S3=108.
      S4=465.
      S5=544.
      S6=201.
      S7=303.
      TA=8.5E-5
      TB=2.1E-2
      TEXCOEF=.5
      TGRAREA=.03
      TGRSHDE=0.
      TLAI=1.
      TRAD=.1
      TSHADE=0.
      TTRANS=.15
      TUTILIZ=11.5E-3
      TX=2.4E-3
      TY=1.9E-2
*
 10   CONTINUE
*
* RESET KOUNTER EVERY 3 HOURS. THIS MEANS THAT SHADE IS CALLED ONLY
* EVERY 3 HOURS.
*
      IF(COUNTER.LE.3) KOUNTER=1
      IF(COUNTER.GE.4) KOUNTER=2
      IF(COUNTER.GE.7) KOUNTER=3
      IF(COUNTER.GE.10) KOUNTER=4
      IF(COUNTER.GE.13) KOUNTER=5
      IF(COUNTER.GE.16) KOUNTER=6
      IF(COUNTER.GE.19) KOUNTER=7
      IF(COUNTER.GE.22) KOUNTER=8
*
* SET TCUMPHD AND BCUMPHD TO 0. AT THE BEGINNING OF EACH DAY
*
      IF(COUNTER.GT.1)GO TO 300
```

```
      TCUMPHD=0.
      BCUMPHD=0.
 300  CONTINUE
*
* INITIALIZE AND THEN INCREMENT CUMENDY OVER THE DAY
*
      IF(COUNTER.EQ.1)CUMENDY=ENERGY(IHR)
      IF(COUNTER.GE.2)CUMENDY=CUMENDY+ENERGY(IHR)
      IF(COUNTER.EQ.1) ECOUNT=0.
      IF(ENERGY(IHR).GT..01) ECOUNT=ECOUNT+1.
*
*                    ***************************
*                    *                         *
*                    *  R E S P I R A T I O N  *
*                    *                         *
*                    ***************************
*
* COMPUTE TLFRESP AND TSTRESP. TLFRESP FUNCTION IS FROM B. ACOCK
* ET AL, J. EXP. BOT. 29 (815-827), 1978, EQUATION 9. SECOND TERM IN
* TRESP FUNCTION IS Q10=2., FROM D. A. HOLT ET AL, PURDUE UNIVERSITY
* AGRICULTURAL EXPERIMENT STATION RESEARCH BULLETIN 907, 1975.
*
      TLFRESP=(TX/(TY*TEXCOEF))*ALOG(((1-TTRANS)+(TY*AVENRGY*TEXCOEF))/(
     +(1-TTRANS)+(TY*AVENRGY*TEXCOEF*EXP(-(TEXCOEF*TLAI)))))
      TSTRESP=TLFRESP/3.
      TRESP=(TLFRESP+TSTRESP)*(2**((TEMP(IHR)-25.)/10.))
*
* COMPUTE BLFRESP AND BSTRESP. SOURCES OF THE EXPRESSIONS ARE THE
* SAME AS FOR TLFRESP AND TRESP ABOVE.
*
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) GO TO 110
*
      BLFRESP=(BX/(BY*BEXCOEF))*ALOG(((1-BTRANS)+(BY*AVENRGY*BEXCOEF))/(
     +(1-BTRANS)+(BY*AVENRGY*BEXCOEF*EXP(-(BEXCOEF*BLAI)))))
      BSTRESP=BLFRESP/3.
      BRESP=(BLFRESP+BSTRESP)*(2**((TEMP(IHR)-25.)/10.))
*
      GO TO 120
*
 110  BLFRESP=0.
      BSTRESP=0.
      BRESP=0.
 120  CONTINUE
*
*             *******************************************
*             *                                         *
*             *  P H O T O S Y N T H E T I C   R A T E  *
*             *                                         *
*             *******************************************
*
* IF ENERGY EQUALS ZERO, SET TPNRATE, STPNRTE AND BPNRATE EQUAL TO THE
* NEGATIVE OF THE APPROPRIATE RESPIRATION RATES. THIS ALLOWS RESPIRATION
* TO PROCEED WHEN PHOTOSYNTHESIS IS SHUT DOWN IN THE DARK. TPHSATE AND
* BPHSATE MAY THEREFORE TAKE ON NEGATIVE VALUES.
*
      IF(ENERGY(IHR).GT..01) GO TO 310
      TPNRATE=-TRESP
      STPNRTE=0.
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) GO TO 130
      BPNRATE=-BRESP
      GO TO 140
```

```
 130  BPNRATE=0.
 140  GO TO 385
 310  CONTINUE
*
* COMPUTE BPNRATE. FUNCTION IS FROM B. ACOCK ET AL, J. EXP.BOT. 29
* (815-827), 1978, EQUATION 8. BPNRATE IS ADJUSTED FOR TEMPERATURE
* EFFECT. TEMPERATURE FUNCTION IS DERIVED FROM P. J. C. KUIPER, PLANT
* PHYSIOL. 40 (915-918), 1965, FIGURE 2.
*
      RATIOT=-.858 + .139*TEMP - .0026*TEMP**2.
      RATIOE=RATIOT
      RATIOP=3.75 - 3.3*ALOG10(LFWPOTL)
      IF(LFWPOTL.LT.6.9) RATIOP=1.
      IF(RATIOP.LT..001) RATIOP=.001
      IF(RATIOP.LT.RATIOE) RATIOE=RATIOP
*
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) GO TO 150
*
      BPART1=(1.-BTRANS)*(BUTILIZ*ENERGY(IHR)+BA*AVENRGY*CO2)
      BPART2=BB*BUTILIZ*ENERGY(IHR)*AVENRGY*BEXCOEF
      BPART3=(BA*CO2)/(BB*BEXCOEF)
      BPART4=EXP(-BEXCOEF*BLAI)
      BPNRATE=(BPART3*ALOG((BPART2+BPART1)/(BPART2*BPART4+BPART1)))*RATI
     +OE - BRESP
*
      GO TO 160
 150  BPNRATE=0.
*
* COMPUTE TPNRATE WITH FULL ENERGY INPUT. SOURCE OF THE EXPRESSION
* IS THE SAME AS FOR THE BPNRATE ABOVE. MATURITY FACTOR REDUCES TOMATO
* PN RATE AFTER 50 DAYS, AND IS ADAPTED FROM D. A. HOLT ET AL, PURDUE
* UNIVERSITY AGRICULTURAL EXPERIMENT STATION RESEARCH BULLETIN 907,
* 1975.
*
 160  TDAY=DAY
      RATIOM=4.30 - 1.94*ALOG10(TDAY)
      IF(DAY.LT.50) RATIOM=1.
*
      TPART1=(1.-TTRANS)*(TUTILIZ*ENERGY(IHR)+TA*AVENRGY*CO2)
      TPART2=TB*TUTILIZ*ENERGY(IHR)*AVENRGY*TEXCOEF
      TPART3=(TA*CO2)/(TB*TEXCOEF)
      TPART4=EXP(-TEXCOEF*TLAI)
      TPNRATE=((TPART3*ALOG((TPART2+TPART1)/(TPART2*TPART4+TPART1)))*RAT
     +IOE)*RATIOM - (TRESP*RATIOM)
*
* COMPUTE BPNRATE AND TPNRATE (CALLED SBPNRTE AND STPNRTE) WITH REDUCED
* ENERGY INPUT DUE TO SHADING. ENERGY IS REDUCED TO 40 PERCENT FULL SUN.
*
      ENSTORE=ENERGY(IHR)
      ENERGY(IHR)=ENERGY(IHR)*.4
*
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) GO TO 161
*
      BPART1=(1.-BTRANS)*(BUTILIZ*ENERGY(IHR)+BA*AVENRGY*CO2)
      BPART2=BB*BUTILIZ*ENERGY(IHR)*AVENRGY*BEXCOEF
      SBPNRTE=(BPART3*ALOG((BPART2+BPART1)/(BPART2*BPART4+BPART1)))*RATI
     +OE - BRESP
      GO TO 162
*
 161  SBPNRTE=0.
*
```

```
 162  CONTINUE
*
      TPART1=(1.-TTRANS)*(TUTILIZ*ENERGY(IHR)+TA*AVENRGY*CO2)
      TPART2=TB*TUTILIZ*ENERGY(IHR)*AVENRGY*TEXCOEF
      STPNRTE=((TPART3*ALOG((TPART2+TPART1)/(TPART2*TPART4+TPART1)))*RAT
     +IOE)*RATIOM - (TRESP*RATIOM)
*
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) STPNRTE=0.
*
      ENERGY(IHR)=ENSTORE
*
*                  ***********************************
*                  *                                 *
*                  *  B E A N   A N D   T O M A T O  *
*                  *          S H A D I N G          *
*                  *                                 *
*                  ***********************************
*
* COMPUTE BEAN HEIGHT. REGRESSION COMES FROM 1980 FIELD DATA.
*
 385  TDIAM=2.*TRAD
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) GO TO 590
      BNHIGHT=.0337 + .572*(BNRADB*2.)
*
* COMPUTE HORIZONTAL LENGTH OF THE BEAN SHADOW. THE RATIO IS SPECIFIC
* FOR 42 DEGREE LATITUDE, TIME OF YEAR AND HOUR.
*
      BNSHADE=BNHIGHT*SHADE(DAY,KOUNTER)
      IF(BNSHADE.GE.HTTDIST) GO TO 500
      TSHADE=TRAD-(HTTDIST-BNSHADE)
      GO TO 550
 500  TSHADE=TRAD+(BNSHADE-HTTDIST)
*
* COMPUTE TOMATO GROUND AREA SHADED BY BEAN
*
 550  IF(BNSHADE.GT.(HTTDIST+TRAD)) GO TO 595
      IF(BNSHADE.GE.HTTDIST) GO TO 560
      IF(TSHADE.LT.0.) GO TO 590
*
      TGRSHDE=(TRAD**2.)*ACOS((TRAD-TSHADE)/TRAD)-((TRAD-TSHADE)*TRAD*
     +SIN(ACOS((TRAD-TSHADE)/TRAD)))
      GO TO 600
 560  IF(BNSHADE.GT.HTTDIST) GO TO 570
      TGRSHDE=(3.1416*(TRAD**2.))/2.
      GO TO 600
 570  TGRSHDE=3.1416*(TRAD**2.) - ((TRAD**2.)*ACOS((TRAD-(BNSHADE-HTTDIS
     +T))/TRAD - (TRAD-(BNSHADE-HTTDIST))*TRAD*SIN(ACOS((TRAD-(BNSHADE-
     +HTTDIST))/TRAD))))
      GO TO 600
 590  TGRSHDE=0.
      TSHADE=0.
      GO TO 600
 595  TGRSHDE=TGRAREA
 600  CONTINUE
*
      IF(BNSHADE.LT.(TTDIST-BNRADB)) GO TO 710
      IF(BNSHADE.GE.(TTDIST-BNRADB).AND.BNSHADE.LT.TTDIST) GO TO 720
      IF(BNSHADE.GE.TTDIST) GO TO 730
 710  BCANSHD=0.
      BFRCTSH=0.
      GO TO 760
```

```
 720  BCANSHD=((BNSHADE - TTDIST + BNRADB)*BNHIGHT)/BNSHADE
      GO TO 750
 730  BCANSHD=((BNSHADE - TTDIST + BNRADB)*BNHIGHT)/BNSHADE
 750  IF(BCANSHD.GT.BNHIGHT) BCANSHD=BNHIGHT
      BFRCTSH=BCANSHD/BNHIGHT
 760  CONTINUE
*
*                   *******************************
*                   *                             *
*                   *   P H O T O S Y N T H A T E *
*                   *                             *
*                   *******************************
*
* COMPUTE THE SUM OF THE TOMATO PHOTOSYNTHATE PRODUCED IN THE SHADED
* AND UNSHADED PORTIONS OF THE CANOPY BY MULTIPLYING TPNRATE AND
* STPNRATE BY GROUND AREA. THE CONSTANT, 2.46, CONVERTS PHOTOSYNTHETIC
* RATE FROM S**-1 TO HR**-1, AND MG CO2 TO G GLUCOSE.
*
      IF(ENERGY(IHR).LT..01) GO TO 390
      TPHSATE=(TPNRATE*(TGRAREA-TGRSHDE)+STPNRTE*TGRSHDE)*2.46
      TCUMPHD=TCUMPHD+TPHSATE
      GO TO 395
 390  TPHSATE=TPNRATE*TGRAREA*2.46
      TCUMPHD=TCUMPHD+TPHSATE
*
* COMPUTE BPHSATE FROM BPNRATE MULTIPLIED BY GROUND AREA. THE CONSTANT,
* 2.46, IS THE SAME AS FOR TPHSATE.
*
 395  IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) GO TO 180
      IF(ENERGY(IHR).LT..01) GO TO 396
      BPHSATE=(BPNRATE*(BGRAREA*(1 - BFRCTSH)) + SBPNRTE*(BGRAREA*BFRCTS
     +H))*2.46
      BCUMPHD=BCUMPHD + BPHSATE
      GO TO 397
 396  BPHSATE=BPNRATE*BGRAREA*2.46
      BCUMPHD=BCUMPHD + BPHSATE
 397  CONTINUE
      GO TO 190
 180  BCUMPHD=0.
      BNHIGHT=0.
      BNSHADE=0.
      BPHSATE=0.
      TGRSHDE=0.
      TSHADE=0.
*
*
* PLACE VARIABLE VALUES INTO ARRAYS FOR LATER PRINTING. ALL VARIABLE
* NAMES STARTING WITH X ARE USED FOR PRINTING ONLY.
*
 190  IF(COUNTER.NE.12.AND.COUNTER.NE.24) GO TO 999
*
      XAVENGY(I)=AVENRGY
      XBCUMPH(I)=BCUMPHD
      XBLFRSP(I)=BLFRESP
      XBNHIGH(I)=BNHIGHT
      XBNPLAN(I)=BNPLANT
      XBNSHDE(I)=BNSHADE
      XBPHSTE(I)=BPHSATE
      XBPNRTE(I)=BPNRATE
      XBRESP(I)=BRESP
      XCOUNTR(I)=COUNTER
```

```
      XDATE(I)=DATE
      XDAY(I)=DAY
      XENERGY(I)=ENERGY(IHR)
      XHARVES(I)=HARVEST
      XI(I)=I
      XIDATE(I)=IDATE
      XIMONTH(I)=IMONTH
      XJDATE(I)=JDATE
      XJMONTH(I)=JMONTH
      XMONTH(I)=MONTH
      XRAIN(I)=RAIN
      XRELHUM(I)=RELHUM(IHR)
      XS1(I)=S1
      XS2(I)=S2
      XS3(I)=S3
      XS4(I)=S4
      XS5(I)=S5
      XS6(I)=S6
      XS7(I)=S7
      XSHADE(I)=SHADE(DAY,KOUNTER)
      XSTPNRT(I)=STPNRTE
      XTCUMPH(I)=TCUMPHD
      XTEMP(I)=TEMP(IHR)
      XTGRSHD(I)=TGRSHDE
      XTLFRSP(I)=TLFRESP
      XTPHSTE(I)=TPHSATE
      XTPNRTE(I)=TPNRATE
      XTRESP(I)=TRESP
      XTSHADE(I)=TSHADE
      XWINDSP(I)=WINDSPD(IHR)
*
 999  CONTINUE
*
      IF(COUNTER.NE.24) GO TO 350
*
* UPDATE AVENRGY TO INCLUDE THE DAY JUST COMPLETED. PREVIOUS VALUE FOR
* S7 IS REPLACED BY PREVIOUS S6, AND SO ON DOWN TO S2. S1 TAKES THE
* NEW VALUE OF AVERAGE ENERGY FOR THAT DAY.
*
      S7=S6
      S6=S5
      S5=S4
      S4=S3
      S3=S2
      S2=S1
      S1=CUMENDY/ECOUNT
      AVENRGY=(S1+S2+S3+S4+S5+S6+S7)/7.
*
 350  CONTINUE
*
      RETURN
      END
*                                                                     *
*                                                                     *
***********************************************************************
*
*
*
***********************************************************************
*                                                                     *
*                                                                     *
```

```
*                          ************************
*                          *                      *
*                          *   SUBROUTINE BNPART  *
*                          *  (BEAN PARTITIONING) *
*                          *                      *
*                          ************************
*
      SUBROUTINE BNPART
*
***********************************************************************
*                                                                     *
*                DEFINITION OF CONSTANTS AND VARIABLES                *
*                                                                     *
* BCHODMD = BEAN CARBOHYDRATE DEMAND FOR LONGTERM STORAGE   G         *
* BCPOOL  = BEAN SHORTTERM CARBOHYDRATE STORAGE   G                   *
* BCSTORE = BEAN LONGTERM CARBOHYDRATE STORAGE   G                    *
* BDRYFR  = BEAN FRUIT DRY WEIGHT   G                                 *
* BDRYLF  = BEAN CANOPY LEAF DRY WEIGHT   G                           *
* BDRYRT  = BEAN ROOT DRY WEIGHT   G                                  *
* BDRYST  = BEAN STEM DRY WEIGHT   G                                  *
* BFRDMD  = BEAN FRUIT DEMAND FUNCTION FOR PARTITIONING               *
*           CARBOHYDRATE   G                                          *
* BFRINCR = BEAN FRUIT DRY MATTER INCREASE   G                        *
* BLFDMD  = BEAN LEAF DEMAND FUNCTION FOR PARTITIONING                *
*           CARBOHYDRATE   G                                          *
* BLFINCR = BEAN LEAF DRY MATTER INCREASE   G                         *
* BNPLANT = BEAN PLANTING DATE IN MODEL DAYS                          *
* BPHSATE = BEAN NET PHOTOSYNTHATE EXPRESSED AS GLUCOSE   G           *
* BRFRDMD = BEAN RELATIVE FRUIT DEMAND FOR PARTITIONING OF            *
*           CARBOHYDRATE                                              *
* BRLFDMD = BEAN RELATIVE LEAF DEMAND FOR PARTITIONING OF             *
*           CARBOHYDRATE                                              *
* BRRTDMD = BEAN RELATIVE ROOT DEMAND FOR PARTITIONING OF             *
*           CARBOHYDRATE                                              *
* BRSTDMD = BEAN RELATIVE STEM DEMAND FOR PARTITIONING OF             *
*           CARBOHYDRATE                                              *
* BRTDMD  = BEAN ROOT DEMAND FUNCTION FOR PARTITIONING                *
*           CARBOHYDRATE   G                                          *
* BRTINCR = BEAN ROOT DRY MATTER INCREASE   G                         *
* BSTDMD  = BEAN STEM DEMAND FUNCTION FOR PARTITIONING                *
*           CARBOHYDRATE   G                                          *
* BSTINCR = BEAN STEM DRY MATTER INCREASE   G                         *
* BSUMDMD = BEAN SUM OF THE COMPONENT PARTITIONING DEMANDS FOR        *
*           CARBOHYDRATE   G                                          *
* BTRLCTE = BEAN CARBOHYDRATE REMOVED FROM SHORTTERM STORAGE FOR      *
*           TRANSLOCATION TO THE VARIOUS COMPONENTS   G               *
* COUNTER = COUNT OF NUMBER OF ITERATIONS DURING A PARTICULAR DAY     *
* DAY     = DAYS AFTER COMMENCEMENT OF THE SIMULATION (FIRST DAY      *
*           IS DEFINED AS DAY 1)   DAY                                *
* HARVEST = BEAN HARVEST DATE IN MODEL DAYS                           *
* IBNDAY  = NUMBER OF BEAN DAYS AFTER BNPLANT                         *
* POOLCHK = MINIMUM CARBOHYDRATE LEVEL ALLOWED IN SHORTTERM STORAGE  G *
*                                                                     *
***********************************************************************
*
* ESTABLISH REAL AND INTEGER VARIABLES
*
      INTEGER COUNTER,DAY,PRINTYP,XCOUNTR,XDAY,XI,XMONTH,XDATE,XJMONTH,
     +XJDATE,XIMONTH,XIDATE,DATE,BNPLANT,HARVEST,XBNPLAN,XHARVES
      REAL MBNRADB,LFWPOTL
*
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* ESTABLISH COMMON BLOCKS
*
      COMMON /MAIN/ BBDIST,BDRYFR,BDRYLF,BDRYRT,BDRYST,BGRAREA,BLAI,
     +BNRADA,BNRADB,BPHSATE,COUNTER,ENERGY(24),HTTDIST,RAIN,
     +RELHUM(24),TDRYFR,TDRYLF,TDRYRT,TDRYST,TEMP(24),TGRAREA,TLAI,
     +TPHSATE,TRAD,TTDIST,WINDSPD(24),I,SHADE(101,8),IHR,DAY,LFWPOTL,
     +HBBDIST,MONTH,DATE,IMONTH,IDATE,JMONTH,JDATE,BNPLANT,HARVEST
*
      COMMON /BNPART/XPOOLCK(180),XBCHODM(180),XBCPOOL(180),
     +XBCSTOR(180),XBDRYFR(180),XBDRYRT(180),XBDRYST(180),XBDRYLF(180),
     +XBFRDMD(180),XBFRINC(180),XBLFDMD(180),XBLFINC(180),XBPHSAT(180),
     +XBRFRDM(180),XBRLFDM(180),XBRRTDM(180),XBRSTDM(180),XBRTDMD(180),
     +XBRTINC(180),XBSTDMD(180),XBSTINC(180),XBSUMDM(180),XBTRLCT(180)
*
* INITIALIZE CONSTANTS AND VARIABLES
*
      BTRLCTE=0.
*
      IF(I.GT.0.OR.COUNTER.GT.1) GO TO 10
*
      BCPOOL=0.
      BCSTORE=0.
      BDRYFR=0.
      BDRYLF=0.
      BDRYRT=0.
      BDRYST=0.
      BFRDMD=0.
      BFRINCR=0.
      BRFRDMD=0.
*
 10   IF(DAY.NE.BNPLANT.OR.COUNTER.NE.1) GO TO 11
      BCPOOL=.05
      BCSTORE=.1
      BDRYFR=0.
      BDRYLF=.3
      BDRYRT=.1
      BDRYST=.15
      BFRDMD=0.
      BFRINCR=0.
      BRFRDMD=0.
*
 11   IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) GO TO 500
*
* CHECK IF PHOTOSYNTHATE IS GREATER THAN ZERO. IF NOT, NO DEMAND IS
* MADE FOR LONGTERM CARBOHYDRATE STORAGE.
*
      IF(BPHSATE.GT.0.) GO TO 100
*
      BCHODMD=0.
      GO TO 150
*
* PLACE 25 PERCENT OF PHOTOSYNTHATE INTO LONGTERM STORAGE WHEN IT IS
* AVAILABLE.
*
 100  BCHODMD=BPHSATE*.25
 150  BCSTORE=BCSTORE + BCHODMD
*
* ADD BALANCE OF PHOTOSYNTHATE TO SHORTTERM CARBOHYDRATE STORAGE. THE
* BALANCE MAY HAVE EITHER POSITIVE OR NEGATIVE VALUES.
*
      BCPOOL= BCPOOL + BPHSATE - BCHODMD
```

```
*
* CHECK IF SHORTTERM STORAGE HAS BECOME LESS THAN 10 PERCENT OF
* LONGTERM STORAGE LEVEL
*
      POOLCHK=BCSTORE*.1
      IF(BCPOOL.GE.POOLCHK) GO TO 200
*
* REMOVE THE SHORTTERM STORAGE DEFICIT FROM LONGTERM STORAGE
*
      BCSTORE=BCSTORE + BCPOOL
*
* ADD 10 PERCENT OF LONGTERM STORAGE TO SHORTTERM STORAGE
*
      BCPOOL=POOLCHK
      BCSTORE=BCSTORE-BCPOOL
 200  CONTINUE
*
* COMPUTE THE INDIVIDUAL PLANT COMPONENT DEMANDS FOR PHOTOSYNTHATE.
* THE FUNCTIONS ARE FITTED CURVES DERIVED FROM GROWTH CURVE DATA
* COLLECTED BY THE AUTHOR.
*
      IBNDAY=DAY - BNPLANT + 1
      BLFDMD=10**(-.407 + .0425*IBNDAY)
      BSTDMD=10**(-.84 + .0466*IBNDAY)
      BFRDMD=156.3 - 8.73*IBNDAY + .122*(IBNDAY**2.)
      IF(IBNDAY.LT.37)BFRDMD=0.
      IF(IBNDAY.LT.20) BRTDMD=.16*(BSTDMD + BLFDMD + BFRDMD)
      IF(IBNDAY.GE.21.AND.IBNDAY.LE.48) BRTDMD=.11*(BSTDMD + BLFDMD +
     +BFRDMD)
      IF(IBNDAY.GE.49) BRTDMD=.08*(BSTDMD + BLFDMD + BFRDMD)
*
* BALANCE THE VARIOUS DEMANDS TO OBTAIN THEM AS A FRACTION OF 1
*
      BSUMDMD=BRTDMD + BSTDMD + BLFDMD + BFRDMD
*
      BRRTDMD=BRTDMD/BSUMDMD
      BRSTDMD=BSTDMD/BSUMDMD
      BRLFDMD=BLFDMD/BSUMDMD
      BRFRDMD=BFRDMD/BSUMDMD
*
* CHECK IF SHORTTERM STORAGE IS GREATER THAN 10 PERCENT OF LONGTERM
* STORAGE. WHEN IT IS NOT, ALL THE SHORTTERM STORAGE IS ALLOCATED TO
* THE PLANT COMPONENTS AND THE SHORTTERM STORAGE GOES TO ZERO.
*
      IF(BCPOOL.NE.POOLCHK) GO TO 250
*
      BRTINCR=BRRTDMD*BCPOOL
      BSTINCR=BRSTDMD*BCPOOL
      BLFINCR=BRLFDMD*BCPOOL
      BFRINCR=BRFRDMD*BCPOOL
      BCPOOL=BCPOOL - (BRTINCR + BSTINCR + BLFINCR + BFRINCR)
*
* SCALE COMPONENT INCREASES BACK TO ACCOUNT FOR SYNTHESIS RESPIRATION
* LOSSES AND THE PRESENCE OF NON-CARBOHYDRATE MATTER IN THE TISSUES.
*
      BRTINCR=BRTINCR*.75
      BSTINCR=BSTINCR*.75
      BLFINCR=BLFINCR*.75
      BFRINCR=BFRINCR*.75
      GO TO 300
*
```

```
* WHEN SHORTTERM STORAGE EXCEEDS 10 PERCENT OF LONGTERM STORAGE, THEN
* 67 PERCENT OF SHORTTERM STORAGE IS TRANSLOCATED. THIS REPRESENTS UP TO
* 50 PERCENT OF THE ORIGINAL PHOTOSYNTHATE PRODUCED IN THE PARTICULAR
* ITERATION.
*
 250  CONTINUE
      BTRLCTE=BCPOOL*.67
      BCPOOL=BCPOOL - BTRLCTE
*
      BRTINCR=BRRTDMD*BTRLCTE*.75
      BSTINCR=BRSTDMD*BTRLCTE*.75
      BLFINCR=BRLFDMD*BTRLCTE*.75
      BFRINCR=BRFRDMD*BTRLCTE*.75
*
 300  CONTINUE
*
* ADD COMPONENT INCREASES TO THEIR APPROPRIATE STATE VARIABLES.
*
      BDRYRT=BDRYRT + BRTINCR
      BDRYST=BDRYST + BSTINCR
      BDRYLF=BDRYLF + BLFINCR
      BDRYFR=BDRYFR + BFRINCR
*
* PLACE VARIABLE VALUES INTO ARRAYS FOR LATER PRINTING. ALL VARIABLE
* NAMES STARTING WITH X ARE USED FOR PRINTING ONLY.
*
 500  IF(COUNTER.NE.12.AND.COUNTER.NE.24) GO TO 999
*
      IF(DAY.GE.BNPLANT) GO TO 510
*
      XBCHODM(I)=0.
      XBCPOOL(I)=0.
      XBCSTOR(I)=0.
      XBDRYFR(I)=0.
      XBDRYLF(I)=0.
      XBDRYRT(I)=0.
      XBDRYST(I)=0.
      XBFRDMD(I)=0.
      XBFRINC(I)=0.
      XBLFDMD(I)=0.
      XBLFINC(I)=0.
      XBPHSAT(I)=0.
      XBRFRDM(I)=0.
      XBRLFDM(I)=0.
      XBRRTDM(I)=0.
      XBRSTDM(I)=0.
      XBRTDMD(I)=0.
      XBRTINC(I)=0.
      XBSTDMD(I)=0.
      XBSTINC(I)=0.
      XBSUMDM(I)=0.
      XBTRLCT(I)=0.
      XPOOLCK(I)=0.
      GO TO 999
*
 510  IF(DAY.GT.HARVEST) GO TO 520
*
      XBCHODM(I)=BCHODMD
      XBCPOOL(I)=BCPOOL
      XBCSTOR(I)=BCSTORE
      XBDRYFR(I)=BDRYFR
```

```
      XBDRYLF(I)=BDRYLF
      XBDRYRT(I)=BDRYRT
      XBDRYST(I)=BDRYST
      XBFRDMD(I)=BFRDMD
      XBFRINC(I)=BFRINCR
      XBLFDMD(I)=BLFDMD
      XBLFINC(I)=BLFINCR
      XBPHSAT(I)=BPHSATE
      XBRFRDM(I)=BRFRDMD
      XBRLFDM(I)=BRLFDMD
      XBRRTDM(I)=BRRTDMD
      XBRSTDM(I)=BRSTDMD
      XBRTDMD(I)=BRTDMD
      XBRTINC(I)=BRTINCR
      XBSTDMD(I)=BSTDMD
      XBSTINC(I)=BSTINCR
      XBSUMDM(I)=BSUMDMD
      XBTRLCT(I)=BTRLCTE
      XPOOLCK(I)=POOLCHK
*
 520  IF(DAY.LE.HARVEST) GO TO 999
*
      XBCHODM(I)=0.
      XBCPOOL(I)=BCPOOL
      XBCSTOR(I)=BCSTORE
      XBDRYFR(I)=BDRYFR
      XBDRYLF(I)=BDRYLF
      XBDRYRT(I)=BDRYRT
      XBDRYST(I)=BDRYST
      XBFRDMD(I)=0.
      XBFRINC(I)=0.
      XBLFDMD(I)=0.
      XBLFINC(I)=0.
      XBPHSAT(I)=0.
      XBRFRDM(I)=BRFRDMD
      XBRLFDM(I)=BRLFDMD
      XBRRTDM(I)=BRRTDMD
      XBRSTDM(I)=BRSTDMD
      XBRTDMD(I)=0.
      XBRTINC(I)=0.
      XBSTDMD(I)=0.
      XBSTINC(I)=0.
      XBSUMDM(I)=0.
      XBTRLCT(I)=0.
      XPOOLCK(I)=0.
*
 999  CONTINUE
*
      RETURN
      END
*                                                                      *
*                                                                      *
************************************************************************
*
*
*
************************************************************************
*                                                                      *
*                                                                      *
*                    ****************************
*                    *                          *
```

```
*                    *   SUBROUTINE TOMPART    *
*                    *  (TOMATO PARTITIONING)  *
*                    *                         *
*                    ***************************
      SUBROUTINE TOMPART
*
***********************************************************************
*                                                                     *
*                DEFINITION OF CONSTANTS AND VARIABLES                *
*                                                                     *
* COUNTER = COUNT OF NUMBER OF ITERATIONS DURING A PARTICULAR DAY     *
* DAY     = DAYS AFTER COMMENCEMENT OF THE SIMULATION (FIRST DAY      *
*           IS DEFINED AS DAY 1)    DAY                               *
* POOLCHK = MINIMUM CARBOHYDRATE LEVEL ALLOWED IN SHORTTERM STORAGE  G *
* TCHODMD = TOMATO CARBOHYDRATE DEMAND FOR LONGTERM STORAGE   G       *
* TCPOOL  = TOMATO SHORTTERM CARBOHYDRATE STORAGE   G                 *
* TCSTORE = TOMATO LONGTERM CARBOHYDRATE STORAGE   G                  *
* TDRYFR  = TOMATO FRUIT DRY WEIGHT   G                               *
* TDRYLF  = TOMATO CANOPY LEAF DRY WEIGHT   G                         *
* TDRYRT  = TOMATO ROOT DRY WEIGHT   G                                *
* TDRYST  = TOMATO STEM DRY WEIGHT   G                                *
* TFRDMD  = TOMATO FRUIT DEMAND FUNCTION FOR PARTITIONING             *
*           CARBOHYDRATE   G                                          *
* TFRINCR = TOMATO FRUIT DRY MATTER INCREASE   G                      *
* TLFDMD  = TOMATO LEAF DEMAND FUNCTION FOR PARTITIONING              *
*           CARBOHYDRATE   G                                          *
* TLFINCR = TOMATO LEAF DRY MATTER INCREASE   G                       *
* TPHSATE = TOMATO NET PHOTOSYNTHATE EXPRESSED AS GLUCOSE   G         *
* TRFRDMD = TOMATO RELATIVE FRUIT DEMAND FOR PARTITIONING OF          *
*           CARBOHYDRATE                                              *
* TRLFDMD = TOMATO RELATIVE LEAF DEMAND FOR PARTITIONING OF           *
*           CARBOHYDRATE                                              *
* TRRTDMD = TOMATO RELATIVE ROOT DEMAND FOR PARTITIONING OF           *
*           CARBOHYDRATE                                              *
* TRSTDMD = TOMATO RELATIVE STEM DEMAND FOR PARTITIONING OF           *
*           CARBOHYDRATE                                              *
* TRTDMD  = TOMATO ROOT DEMAND FUNCTION FOR PARTITIONING              *
*           CARBOHYDRATE   G                                          *
* TRTINCR = TOMATO ROOT DRY MATTER INCREASE   G                        *
* TSTDMD  = TOMATO STEM DEMAND FUNCTION FOR PARTITIONING              *
*           CARBOHYDRATE   G                                          *
* TSTINCR = TOMATO STEM DRY MATTER INCREASE   G                       *
* TSUMDMD = TOMATO SUM OF THE COMPONENT PARTITIONING DEMANDS FOR      *
*           CARBOHYDRATE   G                                          *
* TTRLCTE = TOMATO CARBOHYDRATE REMOVED FROM SHORTTERM STORAGE FOR    *
*           TRANSLOCATION TO THE VARIOUS COMPONENTS   G               *
*                                                                     *
***********************************************************************
*
* ESTABLISH REAL AND INTEGER VARIABLES
*
      INTEGER COUNTER,DAY,PRINTYP,XCOUNTR,XDAY,XI,XMONTH,XDATE,XJMONTH,
     +XJDATE,XIMONTH,XIDATE,DATE,BNPLANT,HARVEST,XBNPLAN,XHARVES
      REAL MBNRADB,LFWPOTL
*
* ESTABLISH COMMON BLOCKS
*
      COMMON /MAIN/ BBDIST,BDRYFR,BDRYLF,BDRYRT,BDRYST,BGRAREA,BLAI,
     +BNRADA,BNRADB,BPHSATE,COUNTER,ENERGY(24),HTTDIST,RAIN,
     +RELHUM(24),TDRYFR,TDRYLF,TDRYRT,TDRYST,TEMP(24),TGRAREA,TLAI,
     +TPHSATE,TRAD,TTDIST,WINDSPD(24),I,SHADE(101,8),IHR,DAY,LFWPOTL,
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```
     +HBBDIST,MONTH,DATE,IMONTH,IDATE,JMONTH,JDATE,BNPLANT,HARVEST
*
      COMMON /TOMPART/XPOOLCH(180),XTCHODM(180),
     +XTCPOOL(180),XTCSTOR(180),XTDRYFR(180),XTDRYRT(180),XTDRYLF(180),
     +XTDRYST(180),XTFRDMD(180),XTFRINC(180),XTLFDMD(180),XTLFINC(180),
     +XTPHSAT(180),XTRFRDM(180),XTRLFDM(180),XTRRTDM(180),XTRSTDM(180),
     +XTRTDMD(180),XTRTINC(180),XTSTDMD(180),XTSTINC(180),XTSUMDM(180),
     +XTTRLCT(180)
*
* INITIALIZE CONSTANTS AND VARIABLES
*
      TTRLCTE=0.
*
      IF(I.GT.0.OR.COUNTER.GT.1) GO TO 10
*
      TCPOOL=.05
      TCSTORE=.2
      TDRYFR=0.
      TDRYLF=.5
      TDRYRT=.15
      TDRYST=.4
      TFRDMD=0.
      TFRINCR=0.
      TRFRDMD=0.
*
 10   CONTINUE
*
* CHECK IF PHOTOSYNTHATE IS GREATER THAN ZERO. IF NOT, NO DEMAND IS
* MADE FOR LONGTERM CARBOHYDRATE STORAGE.
*
      IF(TPHSATE.GT.0.) GO TO 100
*
      TCHODMD=0.
      GO TO 150
*
* PLACE 25 PERCENT OF PHOTOSYNTHATE INTO LONGTERM STORAGE WHEN IT IS
* AVAILABLE.
*
 100  TCHODMD=TPHSATE*.25
 150  TCSTORE=TCSTORE + TCHODMD
*
* ADD BALANCE OF PHOTOSYNTHATE TO SHORTTERM CARBOHYDRATE STORAGE. THE
* BALANCE MAY HAVE EITHER POSITIVE OR NEGATIVE VALUES.
*
      TCPOOL= TCPOOL + TPHSATE - TCHODMD
*
* CHECK IF SHORTTERM STORAGE HAS BECOME LESS THAN 10 PERCENT OF
* LONGTERM STORAGE LEVEL
*
      POOLCHK=TCSTORE*.1
      IF(TCPOOL.GE.POOLCHK) GO TO 200
*
* REMOVE THE SHORTTERM STORAGE DEFICIT FROM LONGTERM STORAGE
*
      TCSTORE=TCSTORE + TCPOOL
*
* ADD 10 PERCENT OF LONGTERM STORAGE TO SHORTTERM STORAGE
*
      TCPOOL=POOLCHK
      TCSTORE=TCSTORE-TCPOOL
 200  CONTINUE
```

```
*
* COMPUTE THE INDIVIDUAL PLANT COMPONENT DEMANDS FOR PHOTOSYNTHATE.
* THE FUNCTIONS ARE FITTED CURVES DERIVED FROM GROWTH CURVE DATA
* COLLECTED BY THE AUTHOR.
*
      TLFDMD=.882 + .308*DAY + .0269*(DAY**2.)
      TSTDMD=1.17 + .274*DAY + .0161*(DAY**2.)
      TFRDMD=47.3 - 5.1*DAY + .138*(DAY**2.)
      IF(DAY.LT.19) TFRDMD=0.
      IF(DAY.LT.20) TRTDMD=.16*(TSTDMD + TLFDMD + TFRDMD)
      IF(DAY.GE.21.AND.DAY.LE.48) TRTDMD=.11*(TSTDMD + TLFDMD + TFRDMD)
      IF(DAY.GE.49) TRTDMD=.08*(TSTDMD + TLFDMD + TFRDMD)
*
* BALANCE THE VARIOUS DEMANDS TO OBTAIN THEM AS A FRACTION OF 1
*
      TSUMDMD=TRTDMD + TSTDMD + TLFDMD + TFRDMD
*
      TRRTDMD=TRTDMD/TSUMDMD
      TRSTDMD=TSTDMD/TSUMDMD
      TRLFDMD=TLFDMD/TSUMDMD
      TRFRDMD=TFRDMD/TSUMDMD
*
* CHECK IF SHORTTERM STORAGE IS GREATER THAN 10 PERCENT OF LONGTERM
* STORAGE. WHEN IT IS NOT, ALL THE SHORTTERM STORAGE IS ALLOCATED TO
* THE PLANT COMPONENTS AND THE SHORTTERM STORAGE GOES TO ZERO.
*
      IF(TCPOOL.NE.POOLCHK) GO TO 250
*
      TRTINCR=TRRTDMD*TCPOOL
      TSTINCR=TRSTDMD*TCPOOL
      TLFINCR=TRLFDMD*TCPOOL
      TFRINCR=TRFRDMD*TCPOOL
      TCPOOL=TCPOOL - (TRTINCR + TSTINCR + TLFINCR + TFRINCR)
*
* SCALE COMPONENT INCREASES BACK TO ACCOUNT FOR SYNTHESIS RESPIRATION
* LOSSES AND THE PRESENCE OF NON-CARBOHYDRATE MATTER IN THE TISSUES.
*
      TRTINCR=TRTINCR*.75
      TSTINCR=TSTINCR*.75
      TLFINCR=TLFINCR*.75
      TFRINCR=TFRINCR*.75
      GO TO 300
*
* WHEN SHORTTERM STORAGE EXCEEDS 10 PERCENT OF LONGTERM STORAGE, THEN
* 67 PERCENT OF SHORTTERM STORAGE IS TRANSLOCATED. THIS REPRESENTS UP TO
* 50 PERCENT OF THE ORIGINAL PHOTOSYNTHATE PRODUCED IN THE PARTICULAR
* ITERATION.
*
 250  CONTINUE
      TTRLCTE=TCPOOL*.67
      TCPOOL=TCPOOL - TTRLCTE
*
      TRTINCR=TRRTDMD*TTRLCTE*.75
      TSTINCR=TRSTDMD*TTRLCTE*.75
      TLFINCR=TRLFDMD*TTRLCTE*.75
      TFRINCR=TRFRDMD*TTRLCTE*.75
*
 300  CONTINUE
*
* ADD COMPONENT INCREASES TO THEIR APPROPRIATE STATE VARIABLES.
*
```

```
      TDRYRT=TDRYRT + TRTINCR
      TDRYST=TDRYST + TSTINCR
      TDRYLF=TDRYLF + TLFINCR
      TDRYFR=TDRYFR + TFRINCR
*
* PLACE VARIABLE VALUES INTO ARRAYS FOR LATER PRINTING. ALL VARIABLE
* NAMES STARTING WITH X ARE USED FOR PRINTING ONLY.
*
      IF(COUNTER.NE.12.AND.COUNTER.NE.24) GO TO 999
      XPOOLCH(I)=POOLCHK
      XTCHODM(I)=TCHODMD
      XTCPOOL(I)=TCPOOL
      XTCSTOR(I)=TCSTORE
      XTDRYFR(I)=TDRYFR
      XTDRYLF(I)=TDRYLF
      XTDRYRT(I)=TDRYRT
      XTDRYST(I)=TDRYST
      XTFRDMD(I)=TFRDMD
      XTFRINC(I)=TFRINCR
      XTLFDMD(I)=TLFDMD
      XTLFINC(I)=TLFINCR
      XTPHSAT(I)=TPHSATE
      XTRFRDM(I)=TRFRDMD
      XTRLFDM(I)=TRLFDMD
      XTRRTDM(I)=TRRTDMD
      XTRSTDM(I)=TRSTDMD
      XTRTDMD(I)=TRTDMD
      XTRTINC(I)=TRTINCR
      XTSTDMD(I)=TSTDMD
      XTSTINC(I)=TSTINCR
      XTSUMDM(I)=TSUMDMD
      XTTRLCT(I)=TTRLCTE
 999  CONTINUE
*
      RETURN
      END
*                                                                       *
*                                                                       *
*************************************************************************
*
*
*
*************************************************************************
*                                                                       *
*                                                                       *
*                       ***********************
*                       *                     *
*                       *  SUBROUTINE CANOPY  *
*                       *                     *
*                       ***********************
*
      SUBROUTINE CANOPY
*
*************************************************************************
*                                                                       *
*                  DEFINITION OF CONSTANTS AND VARIABLES                *
*                                                                       *
* BBDIST  = BEAN-BEAN PLANTING DISTANCE   M                             *
* BBMOVLP = MAXIMUM ALLOWABLE OVERLAP OF BEAN-BEAN CANOPIES   M         *
* BBOVLP  = OVERLAP OF THE BEAN-BEAN CANOPIES   M                       *
* BDRYLF  = BEAN CANOPY LEAF DRY WEIGHT   G                             *
```

```
* BGRAREA = AREA UNDER THE BEAN CANOPY   M**2                        *
* BLAI    = BEAN LEAF AREA INDEX                                      *
* BLFAREA = BEAN CANOPY LEAF AREA   M**2                              *
* BNFLAG  = FLAG TO DECLARE THAT BEAN-BEAN OVERLAP HAS REACHED THE    *
*           MAXIMUM ALLOWABLE DISTANCE                                *
* BNPLANT = BEAN PLANTING DATE IN MODEL DAYS                          *
* BNRADA  = BEAN CANOPY RADIUS IN THE DIRECTION OF THE ROW   M        *
* BNRADB  = BEAN RADIUS IN THE DIRECTION PERPENDICULAR TO THE ROW   M *
* BOVAREA = SUM OF OVERLAP GROUND AREA ON BOTH SIDES OF BEAN          *
*           CANOPY   M**2                                             *
* BOVFRCT = BEAN-BEAN OVERLAP AREA AS A FRACTION OF BEAN GROUND AREA  *
* EBDRYLF = EFFECTIVE BEAN LEAF DRY WEIGHT DUE TO BEAN-BEAN           *
*           OVERLAP   G                                               *
* HARVEST = BEAN HARVEST DATE IN MODEL DAYS                           *
* HBBDIST = HALF THE BEAN-BEAN PLANTING DISTANCE   M                  *
* MBNRADB = MAXIMUM ALLOWABLE BEAN CANOPY RADIUS PERPENDICULAR TO     *
*           THE ROW   M                                               *
* MODE    = TYPE OF BEAN GROWTH                                       *
* TBMOVLP = MAXIMUM ALLOWABLE OVERLAP OF TOMATO-BEAN CANOPIES   M     *
* TBOVLP  = OVERLAP OF THE TOMATO-BEAN CANOPIES      M                *
* TDRYLF  = TOMATO CANOPY LEAF DRY WEIGHT   G                         *
* TGRAREA = AREA UNDER THE TOMATO CANOPY   M**2                       *
* TLAI    = TOMATO LEAF AREA INDEX                                    *
* TLFAREA = TOMATO CANOPY LEAF AREA   M**2                            *
* TRAD    = TOMATO CANOPY RADIUS   M                                  *
* TTDIST  = TOMATO-TOMATO PLANTING DISTANCE   M                       *
*                                                                     *
***********************************************************************
*
* ESTABLISH REAL AND INTEGER VARIABLES
*
      INTEGER COUNTER,DAY,PRINTYP,XCOUNTR,XDAY,XI,XMONTH,XDATE,XJMONTH,
     +XJDATE,XIMONTH,XIDATE,DATE,BNPLANT,HARVEST,XBNPLAN,XHARVES
      REAL MBNRADB,LFWPOTL
*
* ESTABLISH COMMON BLOCKS
*
      COMMON /MAIN/ BBDIST,BDRYFR,BDRYLF,BDRYRT,BDRYST,BGRAREA,BLAI,
     +BNRADA,BNRADB,BPHSATE,COUNTER,ENERGY(24),HTTDIST,RAIN,
     +RELHUM(24),TDRYFR,TDRYLF,TDRYRT,TDRYST,TEMP(24),TGRAREA,TLAI,
     +TPHSATE,TRAD,TTDIST,WINDSPD(24),I,SHADE(101,8),IHR,DAY,LFWPOTL,
     +HBBDIST,MONTH,DATE,IMONTH,IDATE,JMONTH,JDATE,BNPLANT,HARVEST
*
      COMMON /CANOPY/IMODE(180),XBNRADA(180),XBNRADB(180),XBGRARA(180),
     +XEBDRYL(180),XBLFARA(180),XBLAI(180),XBBOVLP(180),
     +XBOVARA(180),XBOVFRC(180),XBNFLAG(180),XTRAD(180),XTGRARA(180),
     +XTLFARA(180),XTLAI(180),XTBOVLP(180)
*
* INITIALIZE CONSTANTS AND VARIABLES
*
      IF(I.GT.0.OR.COUNTER.GT.1) GO TO 10
*
      BBMOVLP=.05
      BBOVLP=0.
      BNFLAG=0.
      BNRADA=0.
      BOVAREA=0.
      BOVFRCT=0.
      MBNRADB=.327 + .632*ALOG10(TTDIST)
      MODE=1
      TBOVLP=0.
```

```
      TBMOVLP=.1
*
 10   IF(DAY.NE.BNPLANT.OR.COUNTER.NE.1) GO TO 11
*
      BBMOVLP=.05
      BBOVLP=0.
      BNFLAG=0.
      BNRADA=.03
      BOVAREA=0.
      BOVFRCT=0.
      MBNRADB=.327 + .632*ALOG10(TTDIST)
      MODE=1
      TBOVLP=0.
      TBMOVLP=.1
*
 11   CONTINUE
*
*                     ******************************
*                     *                            *
*                     *  T O M A T O   C A N O P Y *
*                     *                            *
*                     ******************************
*
* IF TOMATO-BEAN OVERLAP EXCEEDS THE MAXIMUM ALLOWABLE DO NOT INCREMENT
* GROUND AREA FURTHER. LEAF AREA INDEX ONLY INCREASES.
*
      IF(TBOVLP.GE.TBMOVLP) GO TO 100
*
* COMPUTE NEW TOMATO GROUND AREA. FUNCTION COMES FROM A REGRESSION OF
* 1980 FIELD DATA BY THE AUTHOR.
*
      TGRAREA=10.**(-1.62 + .685*ALOG10(TDRYLF))
*
* COMPUTE NEW TOMATO RADIUS FROM GROUND AREA
*
      TRAD=SQRT(TGRAREA/3.1416)
      IF(TRAD.GT..5) TRAD=.5
 100  CONTINUE
*
* COMPUTE TOMATO LEAF AREA FROM TOMATO LEAF DRY WEIGHT. FUNCTION COMES
* FROM A REGRESSION OF 1980 FIELD DATA BY THE AUTHOR.
*
      TLFAREA=.0243*TDRYLF - .0143
      IF(TLFAREA.LT..008) TLFAREA=.008
*
* COMPUTE TOMATO LEAF AREA INDEX FROM LEAF AREA AND GROUND AREA
*
      TLAI=TLFAREA/TGRAREA
*
      IF(DAY.LT.BNPLANT.OR.DAY.GT.HARVEST) GO TO 400
*
*                       *************************
*                       *                       *
*                       *  B E A N   C A N O P Y *
*                       *                       *
*                       *************************
*
* IF BEAN RADIUS B EXCEEDS THE MAXIMUM ALLOWABLE LENGTH, DO NOT
* INCREMENT BEAN RADIAL GROWTH IN THE B DIRECTION. GO TO MODE 4.
*
      MBNRADB=.327 + .632*ALOG10(TTDIST)
```

```
      IF(BNRADB.GE.MBNRADB) GO TO 300
*
* COMPUTE NEW BEAN GROUND AREA. FUNCTION COMES FROM A REGRESSION OF
* 1980 FIELD DATA BY THE AUTHOR.
*
      BGRAREA=10.**(-1.79 + .779*ALOG10(BDRYLF))
*
* IF BEAN-BEAN OVERLAP EXCEEDS THE MAXIMUM ALLOWABLE DISTANCE, SWITCH
* TO MODE 3. IN MODE 3, BEAN RADIUS B IS INCREMENTED WHILE BEAN
* RADIUS A IS HELD CONSTANT.
*
      IF(BNFLAG.GE.98.) GO TO 200
*
*                        * * * * * * * * * * *
*                        *                   *
*                        *   M O D E   1     *
*                        *                   *
*                        * * * * * * * * * * *
*
* IN MODE 1, BEAN GROWTH IS CIRCULAR WITH EQUAL INCREASE IN ALL RADII.
* THERE IS NO BEAN-BEAN OVERLAP, AND RADIUS A AND RADIUS B ARE EQUAL.
*
* COMPUTE BEAN RADIUS A AND SET RADIUS B EQUAL TO IT
*
      BNRADA=SQRT(BGRAREA/3.1416)
      BNRADB=BNRADA
*
* IF BEAN RADIUS A EXCEEDS ONE HALF OF THE BEAN-BEAN DISTANCE THEN
* OVERLAP HAS OCCURRED. PROCEED TO MODE 2.
*
      IF(BNRADA.GE.HBEDIST) GO TO 150
*
* SET EFFECTIVE BEAN DRY LEAF EQUAL TO BEAN DRY LEAF
*
      EBDRYLF=BDRYLF
*
* COMPUTE BEAN LEAF AREA FROM BEAN LEAF DRY WEIGHT. FUNCTION COMES
* FROM A REGRESSION OF 1980 FIELD DATA BY THE AUTHOR.
*
      BLFAREA=.0241*BDRYLF - .0062
      IF(BLFAREA.LT..0009) BLFAREA=.0009
*
* COMPUTE BEAN LEAF AREA INDEX FROM LEAF AREA AND GROUND AREA
*
      BLAI=BLFAREA/BGRAREA
*
* COMPUTE TOMATO-BEAN OVERLAP (SHOULD BE NEGATIVE HERE)
*
      TBOVLP=(TRAD+BNRADB)-TTDIST/2.
      MODE=1
      GO TO 400
*
*                        * * * * * * * * * * *
*                        *                   *
*                        *   M O D E   2     *
*                        *                   *
*                        * * * * * * * * * * *
*
* IN MODE 2, BEAN GROWTH IS CIRCULAR WITH EQUAL INCREASE IN ALL RADII.
* THERE IS BEAN-BEAN OVERLAP, AND RADIUS A AND RADIUS B ARE EQUAL.
*
```

```
* COMPUTE BEAN-BEAN OVERLAP
*
 150  BBOVLP=2.*(BNRADA-HBBDIST)
*
* SET FLAG FOR SWITCHING TO MODE 3 GROWTH ON THE NEXT ITERATION
*
      IF(BBOVLP.GE.BBMOVLP) BNFLAG=99.
*
* COMPUTE BEAN-BEAN OVERLAP AREA ON BOTH SIDES OF THE PLANT
*
      BOVAREA=4.*((BNRADA**2.)*ACOS(BBDIST/(2.*BNRADA))-(BBDIST/2.)*BNRA
     +DA*SIN(ACOS(BBDIST/(2.*BNRADA))))
*
* COMPUTE BEAN-BEAN OVERLAP FRACTION
*
      BOVFRCT=BOVAREA/BGRAREA
*
* COMPUTE EFFECTIVE BEAN DRY LEAF DUE TO BEAN-BEAN OVERLAP. THE
* PERCENTAGE IS SCALED DOWN TO 1/3 TO ACCOUNT FOR THE UNEVEN
* DISTRIBUTION OF THE CANOPY OVER THE GROUND AREA. THE LEAF AREA INDEX
* AT THE EDGES OF THE PLANT, WHERE THE OVERLAP OCCURS, IS MUCH LESS
* THAN IN THE CENTER. THIS SAME PATTERN IS FOLLOWED IN THE REST OF
* THE CANOPY SUBROUTINE.
*
      EBDRYLF=(BOVFRCT*BDRYLF*.33)+BDRYLF
*
*
* COMPUTE EFFECTIVE BEAN LEAF AREA FROM EFFECTIVE DRY LEAF WEIGHT
      BLFAREA=.0241*EBDRYLF - .0062
      IF(BLFAREA.LT..0009) BLFAREA=.0009
*
* COMPUTE EFFECTIVE BEAN LEAF AREA INDEX FROM LEAF AREA AND GROUND AREA
*
      BLAI=BLFAREA/BGRAREA
*
* COMPUTE TOMATO-BEAN OVERLAP (SHOULD BE NEGATIVE HERE)
*
      TBOVLP=(TRAD+BNRADB)-TTDIST/2.
      MODE=2
      GO TO 400
*
*                           * * * * * * * * * *
*                           *                 *
*                           *   M O D E   3   *
*                           *                 *
*                           * * * * * * * * * *
*
* IN MODE 3, BEAN GROWTH IS ELLIPTICAL WITH INCREASES ONLY IN BEAN
* RADIUS B.  THERE IS BEAN-BEAN OVERLAP, AND RADIUS A IS HELD CONSTANT.
*
* COMPUTE BEAN RADIUS B FROM BEAN GROUND AREA, HOLDING RADIUS A
* CONSTANT. EXPRESSION IS THE STANDARD FORMULA FOR AN ELLIPSE.
*
 200  BNRADB=BGRAREA/(3.1416*BNRADA)
*
* COMPUTE BEAN-BEAN OVERLAP GROUND AREA ON BOTH SIDES. PARTS A, B AND C
* ARE USED ONLY FOR COMPUTING CONVENIENCE.
*
      PARTA=SQRT(4.*BNRADA**2.-BBDIST**2.)
      PARTB=PARTA/BBDIST
      PARTC=(BNRADB*BBDIST)/(4.*BNRADA)
```

```
      BOVAREA=4.*(BNRADA*BNRADB*ATAN(PARTB)-(PARTC*PARTA))
*
* COMPUTE BEAN-BEAN OVERLAP FRACTION
*
      BOVFRCT=BOVAREA/BGRAREA
*
* COMPUTE EFFECTIVE BEAN DRY LEAF DUE TO BEAN-BEAN OVERLAP
*
      EBDRYLF=(BOVFRCT*BDRYLF*.33)+BDRYLF
*
* COMPUTE EFFECTIVE BEAN LEAF AREA FROM EFFECTIVE DRY LEAF WEIGHT
*
      BLFAREA=.0241*EBDRYLF - .0062
*
* COMPUTE EFFECTIVE BEAN LEAF AREA INDEX FROM LEAF AREA AND GROUND AREA
*
      BLAI=BLFAREA/BGRAREA
*
* COMPUTE TOMATO-BEAN OVERLAP (MAY BECOME POSITIVE AT SOME POINT IN
* THIS MODE)
*
      TBOVLP=(TRAD+BNRADB)-TTDIST/2.
      MODE=3
      GO TO 400
*
*                         * * * * * * * * * *
*                         *                 *
*                         *   M O D E   4   *
*                         *                 *
*                         * * * * * * * * * *
*
* IN MODE 4, THERE IS NO FURTHER LATERAL BEAN GROWTH. BEAN CANOPY
* INCREASES ARE IN LEAF AREA INDEX ONLY.
*
* COMPUTE EFFECTIVE BEAN DRY LEAF DUE TO OVERLAP. BEAN-BEAN OVERLAP
* RETAINS ITS VALUE FROM LAST ITERATION THROUGH MODE 3.
*
 300  EBDRYLF=(BOVFRCT*BDRYLF*.33)+BDRYLF
*
* COMPUTE EFFECTIVE BEAN LEAF AREA FROM EFFECTIVE DRY WEIGHT
*
      BLFAREA=.0241*EBDRYLF - .0062
*
* COMPUTE EFFECTIVE BEAN LEAF AREA INDEX FROM LEAF AREA AND GROUND AREA
*
      BLAI=BLFAREA/BGRAREA
*
* COMPUTE TOMATO-BEAN OVERLAP. THIS VALUE MAY CHANGE IN THIS MODE DUE
* TO INCREASES IN THE TOMATO RADIUS.
*
      TBOVLP=(TRAD+BNRADB)-TTDIST/2.
      MODE=4
 400  IF(DAY.GT.HARVEST) TBOVLP=0.
*
* PLACE VARIABLE VALUES INTO ARRAYS FOR LATER PRINTING. ALL VARIABLE
* NAMES STARTING WITH X OR I ARE USED FOR PRINTING ONLY.
*
      IF(COUNTER.NE.12.AND.COUNTER.NE.24) GO TO 999
*
      IF(DAY.GE.BNPLANT) GO TO 510
*
```

```
      IMODE(I)  =MODE
      XBNRADA(I)=0.
      XBNRADB(I)=0.
      XBGRARA(I)=0.
      XEBDRYL(I)=0.
      XBLFARA(I)=0.
      XBLAI(I)  =0.
      XBBOVLP(I)=0.
      XBOVARA(I)=0.
      XBOVFRC(I)=0.
      XBNFLAG(I)=0.
      XTRAD(I)  =TRAD
      XTGRARA(I)=TGRAREA
      XTLFARA(I)=TLFAREA
      XTLAI(I)  =TLAI
      XTBOVLP(I)=0.
      GO TO 999
*
 510  CONTINUE
*
      IMODE(I)  =MODE
      XBNRADA(I)=BNRADA
      XBNRADB(I)=BNRADB
      XBGRARA(I)=BGRAREA
      XEBDRYL(I)=EBDRYLF
      XBLFARA(I)=BLFAREA
      XBLAI(I)  =BLAI
      XBBOVLP(I)=BBOVLP
      XBOVARA(I)=BOVAREA
      XBOVFRC(I)=BOVFRCT
      XBNFLAG(I)=BNFLAG
      XTRAD(I)  =TRAD
      XTGRARA(I)=TGRAREA
      XTLFARA(I)=TLFAREA
      XTLAI(I)  =TLAI
      XTBOVLP(I)=TBOVLP
*
 999  CONTINUE
*
      RETURN
      END
*                                                                      *
*                                                                      *
************************************************************************
*
*
*
************************************************************************
*                                                                      *
*                                                                      *
*                       **********************
*                       *                    *
*                       *  SUBROUTINE YIELD  *
*                       *                    *
*                       **********************
*
      SUBROUTINE YIELD
*
************************************************************************
*                                                                      *
*                  DEFINITION OF CONSTANTS AND VARIABLES               *
```

```
*                                                                      *
* BBDIST  = BEAN-BEAN PLANTING DISTANCE   M                            *
* BDRYFR  = BEAN FRUIT DRY WEIGHT   G                                  *
* BFRFRT  = BEAN FRESH FRUIT WEIGHT   KG                               *
* BNPLANT = BEAN PLANTING DATE IN MODEL DAYS                           *
* BPOPHEC = BEAN POPULATION PER HECTARE                                *
* BPOPHEX = BEAN POPULATION PER HEXAGON                                *
* BYLDHEC = BEAN YIELD PER HECTARE   KG HECTARE**-1                    *
* BYLDHEX = BEAN YIELD PER HEXAGON   KG HEXAGON**-1                    *
* BYLDM2  = BEAN YIELD PER UNIT AREA   KG M**-2                        *
* HARVEST = BEAN HARVEST DATE IN MODEL DAYS                            *
* HEXAREA = HEXAGON AREA   M**2                                        *
* HEXCIRC = HEXAGON CIRCUMFERENCE   M                                  *
* HEXPHEC = NUMBER OF HEXAGONS PER HECTARE                             *
* HTTDIST = HALF THE TOMATO-TOMATO DISTANCE   M                        *
* SYLDHEC = SUM OF THE YIELDS OF THE TWO SPECIES PER HECTARE   KG      *
* SYLDHEX = SUM OF THE YIELDS OF THE TWO SPECIES PER HEXAGON   KG      *
* SYLDM2  = SUM OF THE YIELDS OF THE TWO SPECIES PER UNIT AREA   KG    *
* TDRYFR  = TOMATO FRUIT DRY WEIGHT   G                                *
* TFRFRT  = TOMATO FRESH FRUIT WEIGHT   KG                             *
* TOTLPOP = TOTAL PLANT POPULATION PER HECTARE                         *
* TPOPLTN = TOMATO POPULATION PER HECTARE                              *
* TTDIST  = TOMATO-TOMATO PLANTING DISTANCE   M                        *
* TYLDHEC = TOMATO YIELD PER HECTARE   KG HECTARE**-1                  *
* TYLDHEX = TOMATO YIELD PER HEXAGON   KG HEXAGON**-1                  *
* TYLDM2  = TOMATO YIELD PER UNIT AREA   KG M**-2                      *
*                                                                      *
************************************************************************
*
* ESTABLISH REAL AND INTEGER VARIABLES
*
      INTEGER COUNTER,DAY,PRINTYP,XCOUNTR,XDAY,XI,XMONTH,XDATE,XJMONTH,
     +XJDATE,XIMONTH,XIDATE,DATE,BNPLANT,HARVEST,XBNPLAN,XHARVES
      REAL MBNRADB,LFWPOTL
*
* ESTABLISH COMMON BLOCKS
*
      COMMON /MAIN/ BBDIST,BDRYFR,BDRYLF,BDRYRT,BDRYST,BGRAREA,BLAI,
     +BNRADA,BNRADB,BPHSATE,COUNTER,ENERGY(24),HTTDIST,RAIN,
     +RELHUM(24),TDRYFR,TDRYLF,TDRYRT,TDRYST,TEMP(24),TGRAREA,TLAI,
     +TPHSATE,TRAD,TTDIST,WINDSPD(24),I,SHADE(101,8),IHR,DAY,LFWPOTL,
     +HBBDIST,MONTH,DATE,IMONTH,IDATE,JMONTH,JDATE,BNPLANT,HARVEST
*
      COMMON /YIELD/XBFRFRT(180),XBPOPHC(180),XBPOPHX(180),XBYLDHC(180),
     +XBYLDHX(180),XBYLDM2(180),XHEXARE(180),XHEXCIR(180),XHEXPHE(180),
     +XSYLDHC(180),XSYLDHX(180),XSYLDM2(180),XTFRFRT(180),
     +XTOTLPO(180),XTPOPLT(180),XTYLDHC(180),XTYLDHX(180),XTYLDM2(180),
     +XBBDIST(180),XHTTDIS(180)
*
*
*                   ******************************
*                   *                            *
*                   *  CONVERT FRUIT DRY WEIGHT  *
*                   *             TO             *
*                   *        FRESH WEIGHT        *
*                   *                            *
*                   ******************************
*
* CONVERSION FUNCTIONS COME FROM 1980 DATA COLLECTED BY THE AUTHOR
*
      TFRFRT=(50.5 + 18.9*TDRYFR)/1000.
```

```
      IF(DAY.GT.HARVEST) GO TO 100
      IF(TDRYFR.LT..0001) TFRFRT=0.
      BFRFRT=.014*BDRYFR
*
*                         ***********************
*                         *                     *
*                         *     HEXAGON AREA    *
*                         *         AND         *
*                         *  PLANT POPULATIONS  *
*                         *                     *
*                         ***********************
*
* AREA PER HEXAGON
*
 100  IF(I.GT.0.OR.COUNTER.GT.1) GO TO 200
*
      HEXAREA=3.464*(HTTDIST**2.)
*
* NUMBER OF HEXAGONS PER HECTARE
*
      HEXPHEC=10000./HEXAREA
*
* TOMATO POPULATION PER HECTARE
*
      TPOPLTN=HEXPHEC
*
* BEAN POPULATION PER HEXAGON AND PER HECTARE
*
      HEXCIRC=6.929*HTTDIST
*
      BPOPHEX=HEXCIRC/BBDIST
*
      BPOPHEC=(HEXPHEC*BPOPHEX)/2.
*
* TOTAL POPULATION PER HECTARE
*
      TOTLPOP=TPOPLTN + BPOPHEC
*
*                            *****************
*                            *               *
*                            *  FRESH FRUIT  *
*                            *     YIELD     *
*                            *               *
*                            *****************
*
* YIELD PER HEXAGON
*
 200  TYLDHEX=TFRFRT
*
      BYLDHEX=(BFRFRT*BPOPHEX)/2.
*
* YIELD PER UNIT AREA (M**-2)
*
      TYLDM2=TFRFRT/HEXAREA
*
      BYLDM2=(BFRFRT*BPOPHEX)/(2.*HEXAREA)
*
* YIELD PER HECTARE
*
      TYLDHEC=TYLDM2*10000.
*
```

```
      BYLDHEC=BYLDM2*10000.
*
* SUM OF YIELDS OF BOTH SPECIES
*
* YIELD PER HEXAGON
*
      SYLDHEX=TYLDHEX + BYLDHEX
*
* YIELD PER UNIT AREA (M**-2)
*
      SYLDM2=TYLDM2 + BYLDM2
*
* YIELD PER HECTARE
*
      SYLDHEC=TYLDHEC + BYLDHEC
*
*
* PLACE VARIABLE NAMES INTO ARRAYS FOR LATER PRINTING. ALL VARIABLE
* NAMES STARTING WITH X ARE USED FOR PRINTING ONLY.
*
      IF(COUNTER.NE.12.AND.COUNTER.NE.24) GO TO 999
      XBBDIST(I)=BBDIST
      XBFRFRT(I)=BFRFRT
      XBPOPHC(I)=BPOPHEC
      XBPOPHX(I)=BPOPHEX
      XBYLDHC(I)=BYLDHEC
      XBYLDHX(I)=BYLDHEX
      XBYLDM2(I)=BYLDM2
      XHEXARE(I)=HEXAREA
      XHEXCIR(I)=HEXCIRC
      XHEXPHE(I)=HEXPHEC
      XHTTDIS(I)=HTTDIST
      XSYLDHC(I)=SYLDHEC
      XSYLDHX(I)=SYLDHEX
      XSYLDM2(I)=SYLDM2
      XTFRFRT(I)=TFRFRT
      XTOTLPO(I)=TOTLPOP
      XTPOPLT(I)=TPOPLTN
      XTYLDHC(I)=TYLDHEC
      XTYLDHX(I)=TYLDHEX
      XTYLDM2(I)=TYLDM2
 999  CONTINUE
*
      RETURN
      END
*                                                                      *
*                                                                      *
************************************************************************
```

LIST OF REFERENCES

LIST OF REFERENCES

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