

# A MODEL OF DRY BEAN GROWTH AND DEVELOPMENT: CULTIVAR CARIOCA<sup>1</sup>

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**ABSTRACT** - A simulation model for the dry bean (*Phaseolus vulgaris* L.) indeterminate large guide (type III), cv. carioca is presented and is used to examine the priorities and allocation dynamics of photosynthate. The model is valid for the data of Londrina, PR.

**Index terms:** plant modeling, stochastic model, population dynamics.

## MODELO DE CRESCIMENTO E DESENVOLVIMENTO DO FEIJOEIRO: CULTIVAR CARIOCA

**RESUMO** - Um modelo de simulação de crescimento e desenvolvimento do feijoeiro Carioca (*Phaseolus vulgaris* L.), cultivar de crescimento indeterminado e parcialmente trepador (Tipo III), é usado para examinar as prioridades e a dinâmica da alocação dos produtos da fotossíntese. O modelo é válido para os dados obtidos em Londrina, PR.

**Termos para indexação:** modelagem de plantas, modelo estocástico, dinâmica populacional.

### INTRODUCTION

Dry bean (*Phaseolus vulgaris* L.) is a plant that presents four growth habits: determinate (type I), indeterminate small guide (type II), indeterminate large guide (type III) and indeterminate climbing (type IV).

Bean physiologists attempt to understand plant growth and matter partitioning, using the simplified growth analysis to define with greater precision the contribution of plant type to eventual economic yield (Brandes et al. 1972, Mosjidis 1975, Fanjul et al. 1982). Today mathematical models of field crops are becoming useful tools for a better understanding of the processes of crop growth and yield, and, furthermore, can assess the effects of pests upon these processes. The dry bean model (type III) is similar in both structure and function to a cotton model

described by Gutierrez et al. (1975). Wang et al. (1977) and Gutierrez et al. (1984).

The major objectives of this work were to expand the cotton plant model framework to dry bean, to examine the pattern of photosynthate allocation and to develop a model sufficiently flexible for linking pest models for developing management strategies in dry beans. The mathematical model used by Gutierrez et al. (1984) for cotton and Gutierrez & Baumgaertner (1984a, b) for alfalfa was based on a distributed delay model of Manetsch (1976) and Vansickle (1977). In this model, the distribution developmental times are characterized by an Erlang function.

A canopy model is used with sub-populations of leaves, stem, root and fruit. The model follows the dynamics of all plant parts by age, and in addition includes the number dynamics for fruits. All plant part models are linked via the metabolic pool model for photosynthate allocation, while whole plants are linked via density dependent competition for light, nutrients, water and other resources. Complete information on the metabolic pool model for energy acquisition and allocation can be found in Gutierrez et al. 1987. The model is conceptually a time

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varying life table. While deterministic, it simulates stochastic development.

## MATERIAL AND METHODS

Two plots of 30 m x 15 m of the dry bean, cultivar carioca were planted at a density of ten plants per m<sup>2</sup> on September 2, 1983 at the Experimental Station of the State University of Londrina. The original experiment had irrigated (Plot 1) and unirrigated (Plot 2) plots, but extensive rains fell throughout the season and supplemental irrigation was not needed. The crops were protected from insect injury and diseases by applications of insecticides and fungicides, and agronomic practices were the same in both plots. From each treatment three replicates were randomly selected, consisting of four healthy plants pulled from a meter row, every other day during the crop cycle. The biomass was partitioned into leaf minus petiole, stem plus root, and fruit. The stem samples included the tap root, but no effort was made to collect smaller roots. The leaf area of the plants was estimated using a leaf meter, and the relationship of leaf area to leaf dry matter estimated. Fruit were categorized and counted as buds, flowers and pods. All samples were oven dried for four days at 60°C, then weighed to an accuracy of ±0.01 g. Solar radiation (Cal<sup>-2</sup> day<sup>-1</sup> = 0.484 w/m<sup>2</sup>) and maximum and minimum temperature used to run the model were obtained from the weather station maintained by the Instituto Agronômico do Paraná (IAPAR), Londrina, PR, located at five kilometers from the experimental area. Degree days (°D) calculations were made above a threshold of 5°C, after the method of Frazer & Gilbert (1976).

A separated experiment was used to estimate the maximum pod growth rate. Approximately 500 flowers were isolated and tagged the same day, and ten of them were collected every other day until full growth; the samples were oven dried at 60°C, and weighed. This data was used to estimate rate of pod growth.

## RESULTS AND DISCUSSION

The parameters for the model are given in Table 1. Data from the Plot 1 was used to estimate the parameters, the vegetative

phenology and growth rates, while a separate experiment was used to estimate maximum pod growth rates (Fig. 1 and 2). In Fig. 3 the dry matter leaves, pods and stem plus root (A) and the number of fruit parts (buds, flowers and pods) per plant are presented (B). Leaf and stem plus root production slowed considerably due to carbohydrate stress when the demand for dry matter in pods increased sharply (i.e. the supply - demand ratio). The declines in stem plus roots and leaf dry matter after times 1.100 °D were due to the shedding of senescing leaves and petioles. Apparently the bean plants suffered water stress which causes a faster than normal leaf abscission rate. The declines in late season pod dry matter is explained by the fact that mature

TABLE 1. Parameters for carioca cv. comon bean.

(1) Average longevity of:	Growth rates
Leaves 640°D	0.048 g/°D
Stem (to woody tissue) 1000 °D	0.009 g/°D
Root (to woody tissue) 1000°D	0.006 g/°D
(2) First fruit branch at 10 plants per m <sup>2</sup>	590°D

### (3) Growth demands

#### - Leaf growth ( Δ L)

Δ L mean change in leaf demand from t to t + Δ t

∴ Δ L<sub>t</sub> + Δ t = L<sub>t</sub>.DLP. Δ t = .0085 L<sub>t</sub>. Δ t where DLP is the compounding rate per °D

Δ S<sub>t</sub> + Δ t = L<sub>t</sub>.DSP. Δ t = .099 S<sub>t</sub>. Δ t

#### - Root growth ( Δ R)

Δ R<sub>t</sub> + Δ t DRP. Δ L<sub>t</sub> + Δ t = .125 Δ t + Δ t

- Bud demand (DB); a = age DB = .000569 g/bud/°D = growth rate per bud (0 < a < 355°D)

#### - Fruit demand (DF)

DF = .0037 g/pod/°D = growth rate per pod (355 ≤ a ≤ 1130°D).

TABLE 1. Cont.

(4) Rate of fruit point production (RFP)	
RFP = .4 buds/DD or 0.4. °D per day	
(5) Average developmental times on the phenology of one pod	
Age 0	0
Age 1	175 °D
Age 2	210 °D
Age 3	355 °D
Age 4	1130 °D
Age 5	1355 °D
(6) Shed windows for fruit due to carbohydrate stress	
Buds ( $0 < a < 25$ if $s/d < 1$ )	
Pods ( $150 < a < 700$ °D if $s/d < 1$ )	
	s = supply
	d = demand
(7) 3.3 decimeter square of leaf area per g leaf.	

Pods were not included in the field samples (Fig. 3A). The observed fruit number patterns are presented in Fig. 3B. In beans, the production of new fruits slowed or stopped due to carbohydrate stress when pods began their rapid growth. The fruit dynamics patterns are smoother because of shorter postflower delay in rapid fruit growth. This result is consistent with the extensive data published for cotton by Gutierrez et al. (1975, 1984) and Villacorta et al. (1985).

In Fig. 4 the simulation results are presented, as observed in the field data. Plant subunits grow exponentially until fruits begin rapid growth causing sharp curtailment in growth rates of the other plant subunits. With respect to the dry matter retained, only a small amount is lost via shed fruit; the model predicts that bean may be kept growing vegetatively if enough fruits are removed to

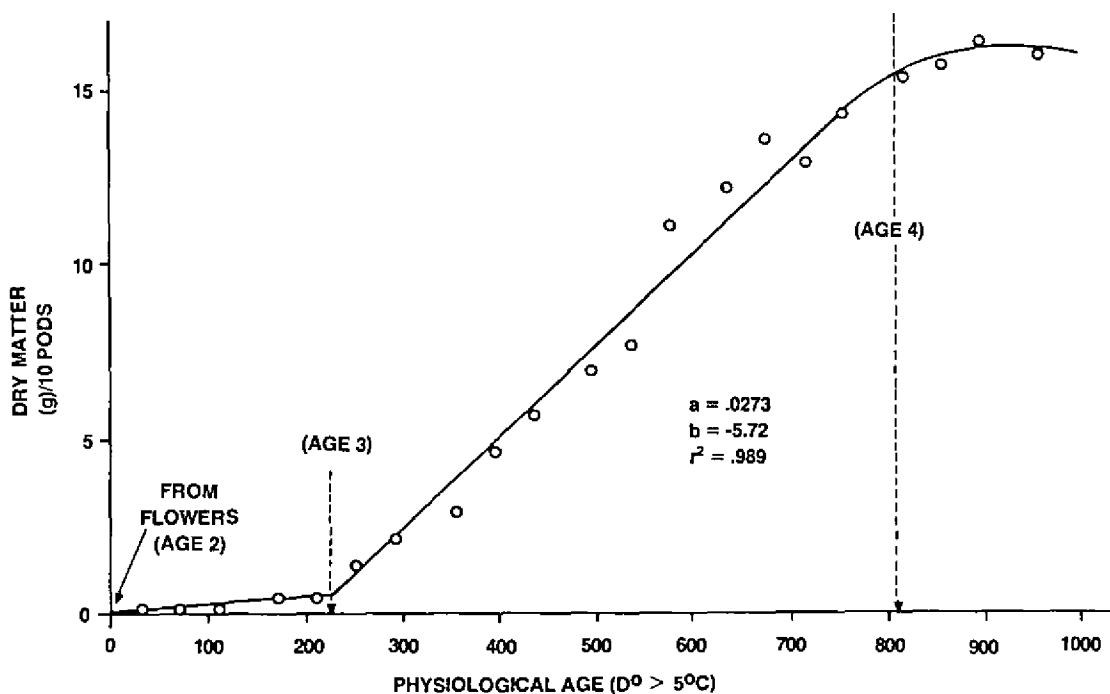


FIG. 1. Average dry matter accumulation in Carioca cv. bean pods plotted on physiological time (°D > 5°C).

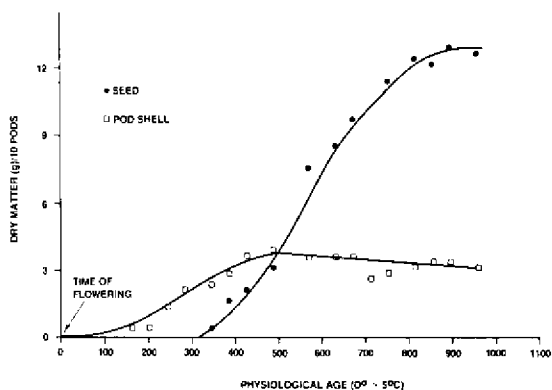


FIG. 2. Average dry matter accumulation in carioca cv. bean, pod shell and seed plotted on physiological time ( $^{\circ}\text{D} > 5^{\circ}\text{C}$ ).

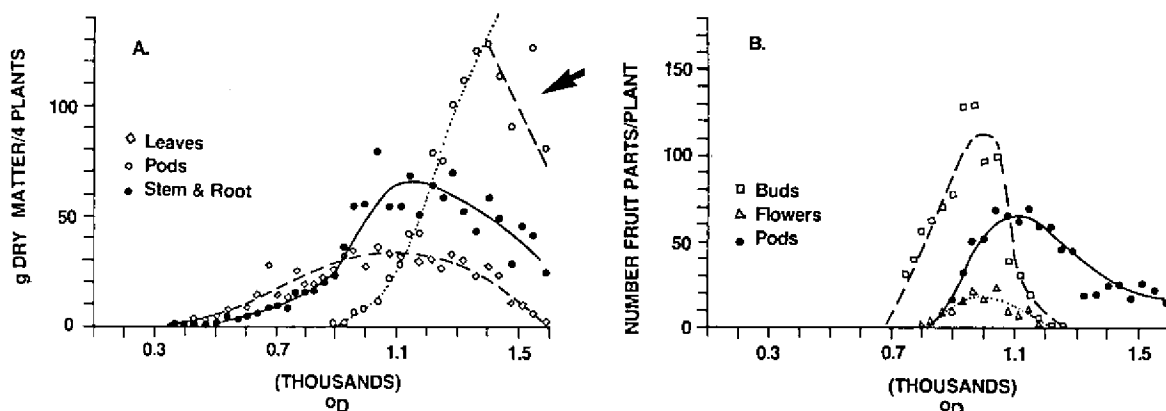


FIG. 3. Dry bean growth and development: A) dry matter allocation to leaves, stem plus root, and pods; B) numbers of fruit buds, flowers and pods. Data plotted on degree days above  $5^{\circ}\text{C}$  using 1983 weather data from Londrina, PR, Brazil. The lines represent simulated values, two arrows indicate discrepancy because in the field sampling of mature pods was not included.

avoid carbohydrate stress. This prediction is consistent with field observations, raising a question about the definitions of determinate and indeterminate growth habits (Fig. 4A). The simulated patterns of age structure and numbers of fruits are presented in Fig. 4B, and follow the patterns observed in the field data.

Daily allocation of dry matter to plant subunits is presented in Fig. 4C. The daily dry matter acquisition and allocation date for

more meaningful picture of allocation emerges from plotting cumulative total allocated respiration and combined growth and reproduction to the total acquired (Fig. 4D). Bean appears to be an efficient plant, assimilating ca. 47% of the energy produced, compared, for example, with 27% in cotton (Gutierrez et al. 1987).

In the model, the stochastic development and the interaction of temperature and solar radiation on bean growth are presented, while water and nitrogen effects are not included. A beans is not available in the literature to validate the simulated information. Daily rates of energy allocation show the dynamics, but a

more advanced model that describes the interactions of cassava, pests and the introduction of natural enemies as modified by weather, soil nitrogen and water levels, is presented by Gutierrez et al. (1988). Nonetheless, with the bean model at its current stage of development, the resultant simulation was highly satisfactory. Presently, the development of the plant model is a prerequisite for evaluating pest damage and

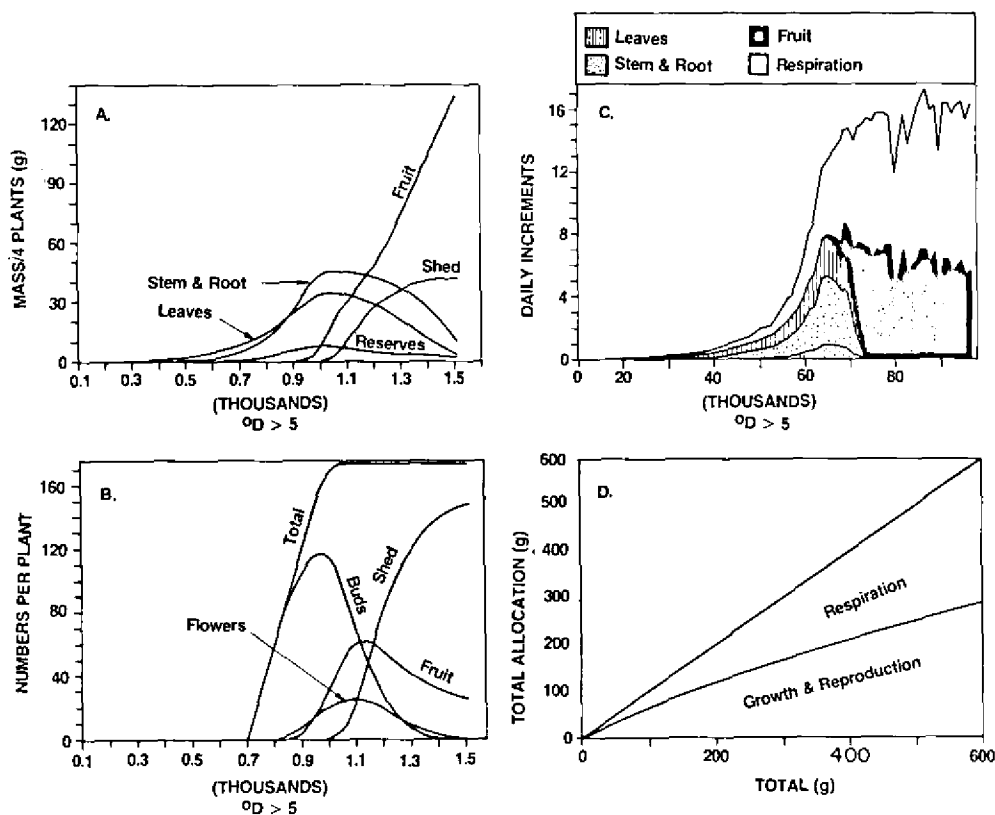


FIG. 4. Per plant simulated dry bean growth and development: A) dry matter allocation to leaves stem plus root reserves, and shed and retained fruit; B) numbers of fruits produced, fruit buds, flowers, pods and total shed fruits; C) daily allocation patterns to plant subunits, and D) allocation fractions. Data plotted on degree days above 5°C using 1983 weather data from Londrina, PR, Brazil.

for developing integrated pest management strategies for their control, leading ultimately to an efficient crop management.

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