Simulation of growth and development of irrigated cowpea in Piauí State by CROPGRO model[1]

Edson Alves Bastos[2], Marcos Vinícius Folegatti[3], Rogério Teixeira de Faria[4], Aderson Soares de Andrade Júnior[2] and Milton José Cardoso[2]

Abstract – The objective of this work was to adapt the CROPGRO model, which is part of the DSSAT system, for simulating the cowpea (*Vigna unguiculata*) growth and development under soil and climate conditions of the Baixo Parnaíba region, Piauí State, Brazil. In the CROPGRO, only input parameters that define crop species, cultivars, and ecotype were changed in order to characterize the cowpea crop. Soil and climate files were created for the considered site. Field experiments without water deficit were used to calibrate the model. In these experiments, dry matter (DM), leaf area index (LAI), yield components and grain yield of cowpea (cv. BR 14 Mulato) were evaluated. The results showed good fit for DM and LAI estimates. The medium values of R^2 and medium absolute error (MAE) were, respectively, 0.95 and 264.9 kg ha^{-1} for DM, and 0.97 and 0.22 for LAI. The difference between observed and simulated values of plant phenology varied from 0 to 3 days. The model also presented good performance for yield components simulation, excluding 100-grain weight, for which the error ranged from 20.9% to 34.3%. Considering the medium values of crop yield in two years, the model presented an error from 5.6%.

Index terms: *Vigna unguiculata*, models, climatic factors, edaphic factor, water availability, DSSAT.

Simulação do crescimento e desenvolvimento do caupi irrigado no Estado do Piauí pelo modelo CROPGRO

Resumo – O objetivo deste trabalho foi adaptar o modelo CROPGRO, o qual faz parte do sistema DSSAT, para simular o crescimento e desenvolvimento do caupi (*Vigna unguiculata*) nas condições de solo e clima do Baixo Parnaíba, Piauí. No CROPGRO, foram modificados apenas parâmetros que definem os arquivos de espécie, de cultivar e de ecótipo, visando caracterizar a cultura do caupi. Foram criados arquivos contendo as características de solo e de clima do referido local. Na calibração do modelo, foram utilizados experimentos de campo sem restrições hídricas nos quais foram avaliados a matéria seca (MS), o índice de área foliar (IAF), os componentes de produção e a produtividade de grãos da cultivar BR 14 Mulato. Os valores médios dos R^2 e do erro absoluto médio (EAM) foram, respectivamente, 0,95 e 264,9 kg ha^{-1} quanto à MS, e 0,97 e 0,22 quanto ao IAF. A diferença entre os valores observados e simulados da fenologia da planta variaram entre 0 e 3 dias. O modelo também apresentou bom desempenho nas simulações dos componentes de produção, exceto quanto ao peso de 100 grãos, cujos erros de estimativa variaram de 20,9% a 34,3%. Considerando os valores médios de produtividade de grãos de dois anos, o modelo apresentou erro de 5,6%.

Termos para indexação: *Vigna unguiculata*, modelo, fator climático, fator edáfico, disponibilidade hídrica, DSSAT.

Introduction

Cowpea is a leguminous and an important source of proteins, present in tropical and subtropical areas (Ehlers & Hall, 1997). In Brazil, cowpea is grown, predominantly, for grain production in the North and Northeast regions, constituting the main subsistence crop of the Brazilian semi-arid region. However, despite its great importance, grain yield of cowpea crop is low, around 300 kg ha^{-1} (Cardoso et al., 1995; Leite et al., 1997).

(1) Accepted for publication on January 31, 2002.

(2) Embrapa-Centro de Pesquisa Agropecuária do Meio-Norte, Caixa Postal 341, CEP 64200-970 Parnaíba, PI. E-mail: edson@cpamn.embrapa.br, aderson@cpamn.embrapa.br, milton@cpamn.embrapa.br

(3) Escola Superior de Agricultura Luiz de Queiroz, Dep. de Engenharia Rural, Caixa Postal 09, CEP 13418-900 Piracicaba, SP. E-mail: mvfolega@carpa.ciagri.usp.br

(4) Instituto Agronômico do Paraná, Rodovia Celso Garcia Cid, Km 375, Caixa Postal 481, CEP 86001-970 Londrina, PR. E-mail: rtfaria@pr.gov.br

Recommendation of new techniques to increase crop yield is time consuming and expensive because it needs evaluation in several locations and years to become a widespread practice. An alternative to solve this problem is the use of crop models that simulate crop yield under different soil and climate conditions. The great advantage of these models is the low cost and the short time spent to obtain results, besides helping a better agricultural planning and management towards higher profits.

The DSSAT (Decision Support System for Agrotechnology Transfer) is a computational system that includes a data base management system, crop models, and application programs. The DSSAT models have been used by a large group of researchers, extension personnel and consultants in various levels of agricultural applications (Hoogenboom et al., 1992). This system includes models for several cereal crops (maize, wheat, sorghum, millet, rice and barley), three legume crops (soybean, peanut and dry bean) and cassava. The grain legume models operate using a generic grain legume model, called CROPGRO. The models require information for soil, climate (maximum and minimum temperatures, precipitation and solar radiation) and crop management conditions (Tsuji et al., 1994).

DSSAT allows the inclusion of other crops by modifications in the specie, cultivar and ecotype files. There are no reliable models for cowpea in the literature.

The objective of this work was to adapt the CROPGRO model for simulating the cowpea growth and development under soil and climate conditions of the Baixo Parnaíba region, Piauí State, Brazil.

Material and Methods

The CROPGRO-cowpea model was established for simulating the growth and development of cowpea crop. This model uses the codes and structure of CROPGRO v. 3.5, as described by Tsuji et al. (1994) and Boote et al. (1998a, 1998b), but the input parameters that define cultivar and ecotype files (Table 1) and specie file (Table 2) were changed in order to characterize the cowpea crop. This information was obtained from the literature and from some experiments carried out at Embrapa-Centro de Pesquisa Agropecuária do Meio-Norte, in Parnaíba, Piauí, Brazil (3º8' S; 41º78' W and 46.8 m elevation). The cowpea files were created by modification of the original files of dry bean (*Phaseolus vulgaris* L.), that is one of the leguminous of CROPGRO. Soil and meteorological data files were created considering the local characteristics. The crop management information, including irrigation management and fertilizer application, as well as planting dates and plant density, were also supplied to the model.

The results of the soils (0-20 cm) chemical analysis were: pH, 6.0; P, 15 mg dm^{-3}; K, 110 mg dm^{-3}; Ca^{2+}, 30 mg dm^{-3}; Mg^{2+}, 13 mg dm^{-3}; Al^{+3}, 0 mg dm^{-3}. The granulometric composition (g kg^{-1}) were: sand, 650; silt, 250;

Table 1. Parameters of cultivar and ecotype files modified for calibration of CROPGRO-cowpea.

Parameters	Values[1]
Cultivar file	
Time between emergence and first flower	36
Time between first flower and first pod	3
Time between first flower and first seed	7
Time between first seed and physiological maturity	17
Time between first flower and end of leaf expansion	12
Specific leaf area of cultivar under standard growth conditions (cm^2 g^{-1})	300
Maximum size of full leaf (three leaflets) (cm^2)	140
Maximum weight per seed (g)	0,16
Seed filling duration	13
Average seed number per pod	15,5
Ecotype file	
Time between planting and emergence (days)	3
Time between emergence and first true leaf (days)	5
Time between physiological and harvest maturity (days)	5
The maximum ratio of seed/(seed + shell) at maturity (%)	78

[1]Values obtained in experiments carried out at Embrapa-Centro de Pesquisa Agropecuária do Meio-Norte, Parnaíba, State of Piauí, Brazil.

Table 2. Species parameters modified from parameters of dry bean (*Phaseolus vulgaris* L.) for calibration of CROPGRO-cowpea model.

Parameters	Values		Reference
	Dry bean	Cowpea	
Photosynthesis parameters			
Light extinction coefficient (KCAN)	0.70	0.85	Wien (1982)
Temperature coefficient (FNPGT)(1)	30	34	Soybean file(2)
Temperature coefficient (FNPGT)(1)	40	45	Soybean file(2)
Leaf specific weight (g cm^{-2}) (SLWREF)	0.0028	0.0033	Local experiment
Leaf N concentration (LNREF)	3.14	3.10	Herridge & Pate (1977)
Plant composition parameters			
Leaf protein concentration (PROLFG)	0.16	0.228	Nielsen et al. (1994)
Stem protein concentration (PROSTG)	0.100	0.09	Nielsen et al. (1994)
Seed protein concentration (SDPROS)	0.235	0.291	Nielsen et al. (1994)
Leaf growth			
Leaf area per three leaflets (cm^2) (SIZREF)	133	140	Local experiment

(1)This coefficient includes four values; only the third and fourth were modified. (2)Correspond to soybean specie file of CROPGRO model.

loam, 100. The bulk density was 1.420 kg m^{-3} and water content (cm^3 cm^{-3}) was 0.171, 0.139 and 0.042 for saturation, field capacity and permanent wilting point conditions, respectively. The climate is tropical humid, with mean annual values of air relative humidity, precipitation and air temperature of 75%, 1,300 mm and 28ºC, respectively.

A field experiment was conducted, using BR 14 Mulato cultivar under four irrigation depths, L1, L2, L3 and L4 (Table 3). The irrigation depths were applied by a line source irrigation system. The experiment was repeated during two years, from June to August of 1997 and from July to October of 1998. A randomized complete block design with four replications was used. The treatment L2, whose water content was maintained near to field capacity, was used to calibrate the model because it provided the largest grain yield (Table 3). Dry matter, leaf area index (LAI), yield components (100 grain weight, number of pod per plant and number of grain per pod) and grain yield of cowpea were evaluated.

Determination coefficient (R^2) and medium absolute error (MAE) were used to evaluate the estimates of leaf area index and dry matter. The yield components and grain yield were evaluated by the difference (%) between predicted and measured values.

Table 3. Irrigation depths applied in different treatment on cowpea (cv. BR 14 Mulato). Parnaíba, State of Piauí, Brazil(1).

Year	L1	L2	L3	L4
1997	455	330	274	190
1998	449	429	317	194

(1)Correspond to treatments used on model calibration; L1, L2, L3 and L4: irrigation depth (mm).

Results and Discussion

Simulation of the plant phenology was quite precise in 1997, with a maximum difference of only two days between observed and simulated data. In 1998, the crop cycle was five days shorter than in 1997, which was not simulated by the model (Table 4). The shorter growing season probably occurred due to high temperatures during 1998 (>38ºC) (Figure 1), reducing the flowering time. However, the results show that the maximum difference between observed and simulated data in 1998, was three days for physiological maturity. The difference between measured and predicted values of numbers of days for appearing of the first flower, first pod and first seed, was only two days (Table 4). Considering that grain yield is directly influenced by the crop cycle and that the difference between simulated and observed grain yield in 1998 was only 9.8% (Table 5), one can affirm that the model presented a satisfactory performance on phenological data simulation. Besides, the observed value of 63 days to complete the physiological maturity is atypical for the Parnaíba conditions. Experiments in previous years in this region, and in Teresina, where air temperature is higher than in Parnaíba, presented physiological maturity between 65 and 70 days. These results would be very close to the simulated data.

The model presented good estimates of DM, reflected by the high determination coefficients (R^2),

Table 4. Phenological data of cv. BR 14 Mulato, during the CROPGRO-cowpea calibration, in 1997 and 1998. Parnaíba, State of Piauí, Brazil.

Phenological data (days after planting)	1997			1998		
	Simulated	Observed	Difference (days)	Simulated	Observed	Difference (days)
First flower	42	42	0	42	40	2
First pod	45	45	0	45	43	2
First seed	49	49	0	49	47	2
Physiological maturity	66	68	-2	66	63	3

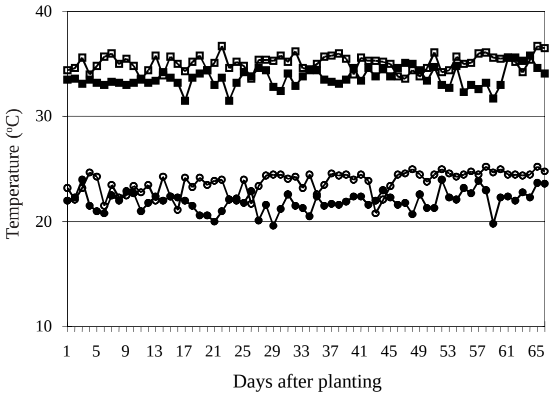

Figure 1. Maximum (□:1998; ■: 1997) and minimum (○: 1998; ●: 1997) temperature values during experiments in 1997 and 1998. Parnaíba, State of Piauí, Brazil.

Table 5. Simulated and observed values of grain yield (kg ha^{-1}) for cv. BR 14 Mulato, during CROPGRO-cowpea calibration, in 1997 and 1998. Parnaíba, State of Piauí, Brazil.

Year	Simulated	Observed	Difference (%)
1997	2,144	2,189	-2.0
1998	1,736	1,924	-9.8
Medium	1,940	2,056	-5.6

which varied from 0.92 to 0.98, and by the relatively low medium absolute error (MAE), ranging from 204.3 to 325.6 kg ha^{-1} (Figure 2).

During the vegetative phase, that extended approximately up to 40 days after planting, simulated and observed dry matter production were very close for both years. However, during the reproductive phase, the differences between predicted and measured data were greater. In this phase, the flowers, pods and seeds appear, increasing the complexity of the system. Therefore, accurate simulation of partitioning of assimilated carbohydrates to plant parts is difficult. Similar results were obtained by Lima (1995) and Barros (1998), whose models accurately simulated dry matter during vegetative phase of a corn crop, but not during reproductive phase.

The model showed an excellent performance in the estimation of LAI, indicated by a high R^2 (0.97) and a low MAE (0.16 to 0.28) (Figure 3).

Observed and simulated LAI values were very low (<0,25) up to 25 days after planting (DAP), indicating low crop growth in this phase. This is a common characteristic in cowpea, as observed by Littleton et al. (1979), Castro et al. (1984), Phogat et al. (1984) and Sivakumar et al. (1996). Soon after, an accelerated vegetative growth was observed, with maximum values of LAI, observed and simulated, varying from 3 to 4.3, in 1997 and 1998, respectively. The number of days to reach the maximum LAI values ranged from 45 to 60 DAP, which is in agreement with the results obtained by Littleton et al. (1979). This variation may be associated with differences in planting date and seasonal variation in the air temperature (Summerfield et al., 1983).

Relatively high deviations were observed in the 100-grain weight estimate, especially in 1998, when the difference between observed and simulated data was 34.3% (Table 6). This happened probably due to high temperature, because, for the model, the reproductive growth rate, as well as the photosynthate translocation, are quite small under high temperatures as observed in 1998. However, there was no significative difference between grain yield observed and estimated. According to Minchin et al. (1980), the P100 does not affect the grain yield so much, which is more influenced by the number of pod per plant (NPP).

The NPP estimates presented small errors in both years: 3.6% in 1997 and 8.0% in 1998 (Table 6). Bastos (1999) also estimated the NPP for cowpea, considering different plant population (4, 9, 14 and 18 plants m^{-2}), with medium error of 8.3%. These results indicate good model accuracy and show that the CROPGRO-cowpea can be used to estimate the cowpea crop grain yield in Piauí State with good confidence level, since NPP is the most important yield component and is very influenced by the plant density.

CROPGRO-cowpea model presented good fit for estimating the number of grain per pod (NGP), with errors ranging from 10.7 to -10.9% (Table 6). Predicted NGP did not vary between years and measured NGP of 1998 was 24.3% higher than the

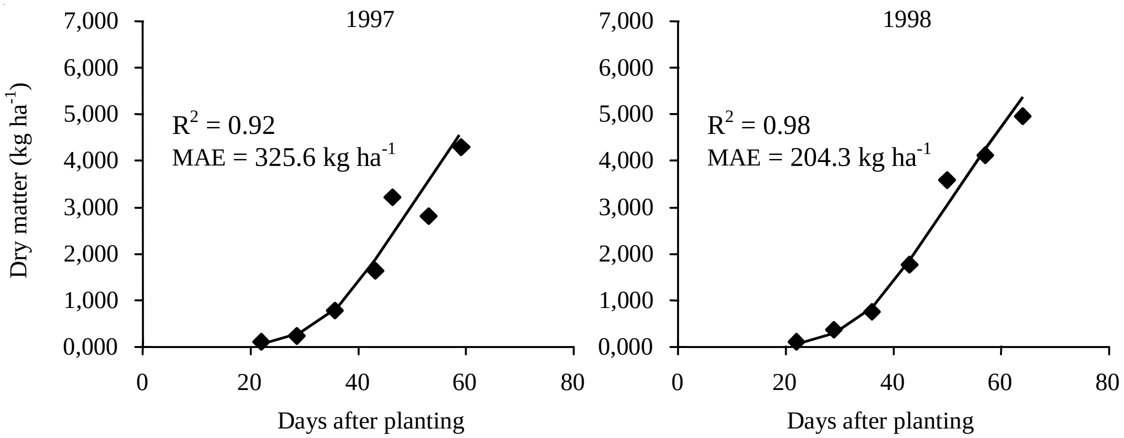

Figure 2. The observed (◆) and simulated (——) cowpea (cv. BR 14 Mulato) dry matter production, in 1997 and 1998. Parnaíba, State of Piauí, Brazil. (MAE: medium absolute error).

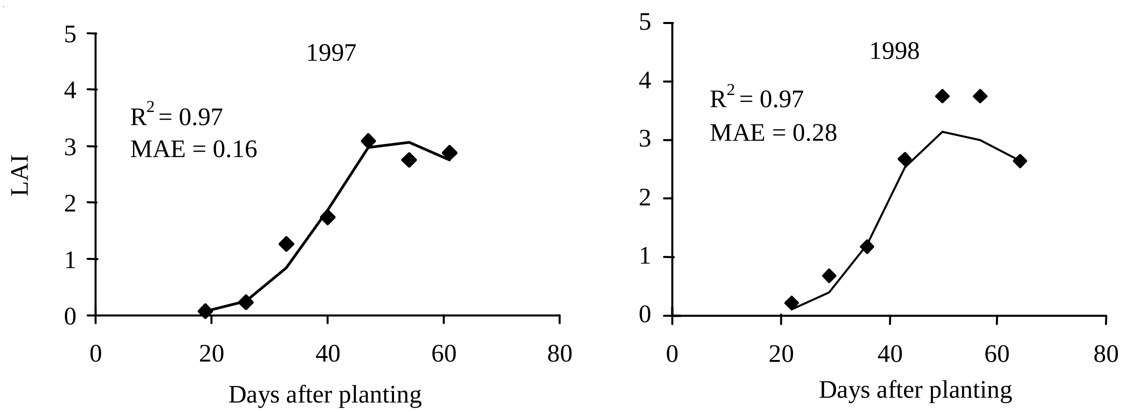

Figure 3. The observed (◆) and simulated (——) cowpea (cv. BR 14 Mulato) leaf area index (LAI), in 1997 and 1998. Parnaíba, State of Piauí, Brazil. MAE (medium absolute error).

Table 6. Predicted and measured yield components for cv. BR 14 Mulato, during CROPGRO-cowpea calibration. Parnaíba, State of Piauí, Brazil.

Yield components(1)	Year	Simulated	Observed	Difference (%)
100GW	1997	11.0	13.9	-20.9
100GW	1998	8.6	13.1	-34.3
NPP	1997	19.3	20.0	-3.6
NPP	1998	16.2	14.9	8.0
NGP	1997	15.5	14.0	10.7
NGP	1998	15.5	17.4	-10.9

(1)100GW: 100-grain weight; NPP: number of pod per plant; NGP: number of grain per pod.

observed value in 1997, even considering the thermal stress occurred in 1998. Thus, it can be concluded that the NGP component is not very sensitive to high air temperatures.

The best fit of grain yield was obtained in 1997, with an error of only 2.0% (Table 5). In 1998, there was a delay in the planting date (7/31/98) in relation to the previous year (6/20/97). Thus, in 1998 the flowering time (about 43 days) of cowpea occurred during a period of high air temperatures (around 35ºC) (Figure 1), that contributed to reduce both observed and simulated grain yields by 12 and 19%, respectively. This was also noted by other authors (Roberts et al., 1978; Summerfield et al., 1978; Doto & Whittington, 1981; Shouse et al., 1981; Sivakumar et al., 1996; Craufurd et al., 1998).

The main problem of the CROPGRO-cowpea is its deficiency in simulating for dry conditions. Another calibration is necessary to supply this gap.

Actually, this model can be used, with reasonable accuracy, to simulate an economic irrigation management for cowpea crop and to choose more favorable planting date. Bastos et al. (2000) applied this model for Parnaíba region and the results showed that 50% of soil-water availability provides the best financial returns. The authors also recommend that the cowpea should be planted from June to September. Another application of the model is to indicate a crop management for different plant population and different manure levels.

Considering the good performance of the model and the possibility in applying it for various aims, one can affirm that the CROPGRO-cowpea is an important tool for helping researchers, producers and technicians to choose the best cowpea management for Baixo Parnaíba region.

Conclusion

CROPGRO-cowpea model simulates satisfactorily the growth and the development of cowpea crop, for the soil and climate conditions of the Baixo Parnaíba, Piauí, Brazil, since there is not water deficit.

References

BARROS, A. H. C. **Análise do crescimento, do desenvolvimento e da produtividade da cultura do milho (*Zea mays* L.)**: experimentos e modelos. 1998. 85 f. Dissertação (Mestrado) - Universidade Federal de Viçosa, Viçosa, MG.

BASTOS, E. A. **Adaptação do modelo CROPGRO para simulação do crescimento e desenvolvimento do feijão caupi (*Vigna unguiculata* (L.) Walp.) sob diferentes condições hídricas, no Estado do Piauí**. 1999. 91 f. Tese (Doutorado) - Escola Superior de Agricultura Luiz de Queiroz, Piracicaba.

BASTOS, E. A.; FOLEGATTI, M. V.; ANDRADE JÚNIOR, A. S. de; CARDOSO, M. J.; FARIA, R. T. Manejo econômico da irrigação de feijão caupi via modelo de simulação. **Revista Irriga**, Botucatu, v. 5, n. 2, p. 84-98, 2000.

BOOTE, K. J.; JONES, J. W.; HOOGENBOOM, G. Simulation of crop growth: CROPGRO model. In: PEART, R. M.; CURRY, R. B. (Ed.). **Agricultural systems modeling and simulation**. New York: M. Dekker, 1998a. p. 651-691.

BOOTE, K. J.; JONES, J. W.; HOOGENBOOM, G.; PICKERING, N. B. The CROPGRO model for grain legumes. In: TSUJI, G. Y.; HOOGENBOOM, G.; THORNTON, P. K. (Ed.). **Understanding options for agricultural production**. Dordrecht: Kluwer, 1998b. p. 99-128.

CARDOSO, M. J.; ANDRADE JÚNIOR, A. S.; MELO, F. B.; FROTA, A. B. **Avaliação agroeconômica da produção de sementes de caupi sob irrigação**. Teresina: Embrapa-CPAMN, 1995. 6 p. (Comunicado Técnico, 62).

CASTRO, P. R. C.; BERGAMASCHI, H.; SILVEIRA, J. A. G.; MARTINS, P. F. S. Desenvolvimento comparado de três cultivares de caupi, *Vigna unguiculata* (L.) Walp. **Anais da Escola Superior de Agricultura Luiz de Queiroz**, Piracicaba, v. 41, n. 2, p. 555-584, 1984.

CRAUFURD, P. Q.; BOJANG, M.; WHELER, T. R.; SUMMERFIELD, R. J. Heat tolerance in cowpea: effect of timing and duration of heat stress. **Annals of Applied Biology**, Wellesbourne, v. 133, p. 257-267, 1998.

DOTO, A. L.; WHITTINGTON, W. J. Responses of cowpea (*Vigna unguiculata*) varieties and their hybrids to variation in day and night temperature regimes. **Annals of Applied Biology**, Wellesbourne, v. 97, p. 213-219, 1981.

EHLERS, J. D.; HALL, A. E. Cowpea (*Vigna unguiculata* L. Walp.). **Field Crops Research**, Amsterdam, v. 53, p. 187-204, 1997.

HERRIDGE, D. F.; PATE, J. S. Utilization of net photosynthate for nitrogen fixation and protein production in an annual legume. **Plant Physiology**, Rockville, v. 60, p. 759-764, 1977.

HOOGENBOOM, G.; JONES, J. W.; BOOTE, K. J. Modeling growth, development, and yield of grain legumes using soygro, pnutgro, and beangro: a review. **Transactions of the ASAE**, Saint Joseph, v. 35, n. 6, p. 2043-2055, 1992.

LEITE, M. L.; RODRIGUES, J. D.; VIRGENS FILHO, J. S. Avaliação de cultivares de caupi (*Vigna unguiculata* (L.) Walp.) quanto à produtividade e componentes de produtividade, sob condições de estufa plástica. **Revista de Agricultura**, Piracicaba, v. 72, n. 3, p. 375-385, 1997.

LIMA, M. G. **Calibração e validação do modelo CERES-maize em condições tropicais do Brasil**. 1995. 119 f. Tese (Doutorado) - Escola Superior de Agricultura Luiz de Queiroz, Piracicaba.

LITTLETON, E. J.; DENNET, M. D.; ELSTON J.; MONTEITH, J. L. The growth and development of cowpeas (*Vigna unguiculata*) under tropical field conditions 1: leaf area. **Journal of Agricultural Science**, Cambridge, England, v. 93, p. 291-307, 1979.

MINCHIN, F. R.; SUMMERFIELD, R. J.; NEVES, C. P. Carbon metabolism, nitrogen assimilation, and seed yield of cowpea (*Vigna unguiculata* L. Walp.) growth in an adverse temperature regime. **Journal of Experimental Botany**, Oxford, v. 31, n. 24, p. 1327-1345, 1980.

NIELSEN, S. S.; OSUALA, C. I.; BRANDT, W. E. Early leaf harvest reduces yield but not protein concentration of cowpea seeds. **HortScience**, Alexandria, v. 29, n. 6, p. 631-632, 1994.

PHOGAT, B. S.; SINGH, D. P.; SINGH, P. Responses of cowpea (*Vigna unguiculata* (L.) Walp.) and mung bean (*Vigna radiata* (L.) Wilczek) to irrigation II: effects on CO_2 exchange, radiation characteristics and growth. **Irrigation Science**, Berlin, v. 5, p. 61-72, 1984.

ROBERTS, E. H.; SUMMERFIELD, R. J.; MINCHIN, F. R.; STEWART, K. A.; NDUNGURU, B. J. Effects of air temperature on seed growth and maturation in cowpea (*Vigna unguiculata*). **Annals of Applied Biology**, Wellesbourne, v. 90, p. 437-446, 1978.

SHOUSE, P.; DASBERG, S.; JURY, W. A.; STOLZY, L. H. Water deficit effects on water potential, yield and water use of cowpeas. **Agronomy Journal**, Madison, v. 73, p. 333-336, 1981.

SIVAKUMAR, M. V. K.; NTARE, B. R.; ROBERTS, J. M. Growth, yield and plant-water relations of four cowpea (*Vigna unguiculata*) cultivars in the Sahel. **Journal of Agricultural Science**, Cambridge, England, v. 126, p. 183-190, 1996.

SUMMERFIELD, R. J.; MINCHIN, F. R.; ROBERTS, E. H.; HADLEY, P. Cowpea. In: SYMPOSIUM ON POTENTIAL PRODUCTIVITY OF FIELD CROPS UNDER DIFFERENT ENVIRONMENTS, 1980, Los Baños. **Proceedings**... Los Baños: International Rice Research Institute, 1983. p. 249-280.

SUMMERFIELD, R. J.; MINCHIN, F. R.; STEWART, K. A.; NDUNGURU, B. J. Growth, reproductive development and yield of effectively nodulated cowpea plants in contrasting aerial environments. **Annals of Applied Biology**, Wellesbourne, v. 90, p. 277-291, 1978.

TSUJI, G. Y.; UEHARA, G.; BALAS, S. (Ed.). **DSSAT v3**. Honolulu: University of Hawaii, 1994. 3 v.

WIEN, H. C. Dry matter production, leaf area development, and light interception of cowpea lines with broad and narrow leaflet shape. **Crop Science**, Madison, v. 22, p. 733-737, 1982.