ELSEVIER

Field Crops Research 39 (1994) 163–170

Field Crops Research

Evaluation of the groundnut model PNUTGRO for crop response to plant population and row spacing

Piara Singh [a,*], K.J. Boote [b], S.M. Virmani [a]

[a] *Soils and Agroclimatology Division, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India*

[b] *Agronomy Department, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611, USA*

Received 20 June 1994; accepted 16 September 1994

Abstract

Field experiments were conducted during the 1987, 1991 and 1992 rainy seasons at Patancheru (latitude 17°32′N; longitude 78°16′E; elevation 545 m), Andhra Pradesh, India, to collect data to test and validate the hedgerow version of the groundnut model PNUTGRO for predicting phenological development, light interception, canopy growth, dry matter production, pod and seed yields of groundnut (*Arachis hypogaea* L.) as influenced by row spacing and plant population. The model was calibrated using the crop growth and phenology data of groundnut (cv. Robut 33-1) obtained from the 1987 and 1991 rainy season experiments. In these experiments groundnut was grown at plant populations ranging from 5 to 45 plants/m^2 with and without irrigation. Changes were made in the cultivar-specific coefficients related to the light penetration into the crop canopy and dry matter production. The model was validated against independent data obtained from a 1992 rainy season experiment. In 1992, groundnut was grown at plant populations ranging from 10 to 40 plants/m^2 and at row spacings of 20, 30 and 60 cm. The model predicted the occurrence of vegetative and reproductive stages, canopy development, total dry matter production and its partitioning to pods and seed accurately. Maximum leaf area index observed during the season was significantly correlated with simulated values ($r^2=0.95$). In spite of some incidence of diseases and pests, the correlation between simulated and observed pod yield was significant ($r^2=0.61$). It is concluded from this study that the hedgerow version of the groundnut model PNUTGRO can be used to quantify groundnut growth and yields as influenced by plant population and row spacing.

Keywords: Groundnut; Modelling; Plant population; Row spacing; Yield prediction

1. Introduction

Groundnut (*Arachis hypogaea* L.) is grown in India in diverse agroclimatic environments characterized by spatial and temporal variations in rainfall and by soils of varying water-retention capacity. The crop is often subject to various patterns and intensities of water deficits during the season. Variations in plant population and row spacing are often needed in these diverse environments to make efficient use of resources and to maximize groundnut production. To optimize the plant population in a given environment, various empirical models have been suggested, which describe crop yield responses to variations in plant population (Holliday, 1960; Willey and Heath, 1969). These models do not incorporate the physical and biological principles determining crop production; consequently the derived empirical coefficients have limited or no biological significance. The empirical models have little predictive

---

* Corresponding author.

SSDI 0378-4290(94)00079-4

value and cannot be used to extrapolate results to other experimental sites. A more robust method for predicting yield responses to differences in plant density and row spacing is through the use of crop simulation models. These typically operate with a daily time step and simulate major components of plant growth and development such as phenology, leaf area development, dry matter production and its partitioning to various plant organs. These models also consider the influence of daily variations in weather affecting the availability of resources such as light, water and nutrients.

Although simulation models have the potential for optimizing planting density, they must be tested and validated in the environments of application before they can be used for crop management. This paper describes the validation of the hedgerow version of the groundnut model PNUTGRO (Boote et al., 1987, 1989, 1992) for its response to row spacing and sowing density in the semi-arid tropical environment of India. The processes considered are vegetative and reproductive development, canopy development, light interception, dry matter production and its partitioning to various organs, and yields at harvest.

2. Model description – the hedgerow sub-model

The basic structure of the model PNUTGRO has been described in several publications (Wilkerson et al., 1983; Boote et al., 1987). The major components of the model are vegetative and reproductive development, carbon balance, nitrogen balance and water balance modules. To simulate groundnut response to row spacing and plant population, Boote et al. (1988, 1989, 1992) revised the light interception and canopy assimilation subroutines to include the hedgerow approach developed by Gijzen and Goudriaan (1989), which was simplified for inclusion in PNUTGRO. This revised model is referred to as the PNUTGRO hedgerow version. Carbon assimilation by hedgerow canopies is described in detail in a paper by Boote and Loomis (1991). This approach predicts canopy light interception, projected shadow cast by the canopy, and the fractions of the leaf area that are sunlit and shaded to estimate carbon assimilation by the crop.

The hedgerow photosynthesis sub-model requires an estimate of canopy geometry. We assumed groundnut has a half-circular cross-section perpendicular to the row that can be described by the apparent canopy height and the apparent canopy width. The rate of height and width increase is proportional to the rate of vegetative stage (V-stage) increase, which in turn is dependent upon temperature and water deficit. The crop parameters file (CROPPARM.PNO) of the model has a ''lookup'' function which describes internode length relative to V-stage development. Internode length is additionally dependent on temperature, water-deficit, solar irradiance, and photoperiod. Groundnut genotypes have differences in growth habit, i.e., erect bunch type, spreading bunch, or spreading runner type. Simple modifiers have been added to the genotype-specific parameters file (GENETICS.PN9) to define canopy width (RWIDTH) and height (RHIGH) of each genotype with respect to a tall spreading runner type (cv. Florunner standard of 1.0). With these functions, differences in light interception associated with various canopy sizes and growth habits of groundnut can be accounted for.

3. Materials and methods

Field experiments were conducted during the 1987, 1991, and 1992 rainy seasons at the ICRISAT center, Patancheru, near Hyderabad (latitude 17°32′N; longitude 78°16′E; elevation 545 m). The plots were located on a deep Alfisol which can retain about 120 mm of plant-extractable water in its rooting zone. Total rainfall in the three seasons (June to November) ranged from 673 to 836 mm and cumulative open-pan evaporation ranged from 931 to 1031 mm. Mean seasonal maximum temperature ranged from 30.2 to 30.9°C and mean seasonal minimum temperature from 21.1 to 21.8°C. Mean daily solar radiation during the growing periods ranged from 16.6 to 17.0 MJ/m^2. Rainfall and open-pan evaporation indicate that the crop was subject to various degrees of water deficit during the three seasons.

3.1. Rainy season experiment 1987

In the 1987 rainy season two groundnut cultivars were sown in a split-split-plot experiment. Main plot treatments consisted of irrigated and rainfed plots, which were further divided into four equal size subplots to which four plant population levels (5, 10, 30 and 45 plants/m^2) were randomly assigned. The subplots were further divided into two sub-sub plots and two cultivars (Robut 33-1 and FDRS 10) were randomly assigned. The experiment was replicated three times. Plot size was 4.2 m×8.5 m. Sowing was done on 13 July in 30-cm east–west rows. Fertilizers at the rate of 20 kg N/ha as urea, 40 kg P/ha as single superphosphate, 60 kg K/ha as KCl, and 25 kg $ZnSO_4$/ha were applied at sowing. Gypsum was applied at the rate of 600 kg/ha at the beginning of pod growth. Irrigated plots received 280 mm of total irrigation during the season, applied on 8, 21, 59, 64, 70, 78, 93 and 107 days after sowing. Rainfed plots received 40 mm of total irrigation for crop establishment at 8 and 21 days after sowing. The crop was harvested on 9 November 1987 from a 9.0-m^2 area per plot to determine yields.

3.2. Rainy season experiment 1991

This experiment had 12 treatments consisting of 3 row spacings (20, 30, and 60 cm) and 4 plant population levels (10, 20, 30, and 40 plants/m^2). The design of the experiment was a randomized complete block with four replications. Plot size was 5.4 m×12 m. Cultivar Robut 33-1 was sown on 24 June in east–west rows. The time and rates of fertilizer application were the same as in 1987. All plots received 215 mm of total irrigation during the season, applied on 67, 72, 81, 84 and 114 days after sowing. The crop was harvested on 30 October 1991 from a 19.2-m^2 area per plot to determine yields.

3.3. Rainy season experiment 1992

This experiment had 9 treatments consisting of 3 row spacings (20, 30, and 60 cm) and 3 plant population levels (10, 20, and 40 plants/m^2). Experimental design was a randomized complete block with three replications. Robut 33-1 was sown on 26 June in east–west rows in 6×12-m plots. Fertilizer application at sowing was 18 kg N/ha and 20 kg P/ha as diammonium phosphate, 60 kg K/ha as KCl, and 25 kg $ZnSO_4$/ha. Additionally, 20 kg P/ha was applied as single superphosphate at sowing. Gypsum at the rate of 500 kg/ha was applied at the beginning of pod growth. The crop received 170 mm of total irrigation during the season applied on 13, 84, 94, 99, and 102 days after sowing. The crop was harvested on 23 October 1992 from a 19.2-m^2 area per plot to determine yields.

3.4. Crop development and growth analysis

Vegetative and reproductive development in each experiment were recorded according to Boote (1982). Five plants in each plot were tagged and the vegetative stages (number of nodes formed on the main branch) were recorded every two days. Reproductive stages were also recorded on the same plants until the beginning of pod growth (R_3). After R_3, the reproductive stages were recorded after uprooting and examining five plants twice weekly in each plot. For growth analysis, plants were harvested from a 0.6- to 0.75-m^2 area during the three seasons. Samples were taken from each plot and washed to remove soil adhering to the pods. From each large sample, a sub-sample of 3–5 plants was taken and plant components separated to determine leaf area and partition of dry matter to plant components such as leaves, stems, pegs, pods, and seeds. After recording leaf area of each sample with a leaf area meter (Model LI-3100, LI-COR Ltd.), all plant components and the remaining part of the large sample were transferred to separate bags and oven dried at 60°C for about a week and then weighed to determine dry matter. Plant sampling for growth analysis was done at 7- to 10-day intervals during each season.

3.5. Light interception

Light interception by the crop in each treatment was recorded by positioning a line quantum sensor (LI-191SB, LI-COR Ltd.) above and below the crop canopy. To record the amount of radiation intercepted by different row spacings, the line quantum sensor was placed across the rows in such a way that its sensor length extended from the middle of one inter-row space to the middle of another. These observations were taken twice weekly at mid-day. Percent interception was calculated from the ratio of the difference between the amount of radiation received above and beneath the canopy to the total incoming radiation.

3.6. Soil moisture

To determine soil moisture content, two neutron probe tubes were installed in each plot. One tube was installed within a row and the other between rows. Observations were taken weekly in each tube from 0.3 to 1.5 m soil depth at 0.15-m intervals. Neutron probe readings at any particular depth represented the moisture content in a soil layer 15 cm thick. Soil moisture was determined gravimetrically in the 0 to 0.15 m and 0.15 to 0.225 m layers.

3.7. Crop protection

The crops were sprayed against diseases and pests during the three seasons. However, it was difficult to completely control diseases, particularly late leaf spot (*Phaeoisariopsis personata*) and rust (*Puccinia arachidis*) during the later phases of crop growth. Therefore, the degree of crop protection achieved varied across seasons.

All data on crop phenology, growth analysis, crop management, and soil moisture were entered in the standard database forms of the Decision Support System for Agrotechnology Transfer (DSSAT) (IBSNAT, 1989) and retrieved to create the input files needed for model execution.

4. Results and discussion

The hedgerow version of the model has been tested by Boote et al. (1988, 1989) for its ability to estimate photosynthesis as influenced by row spacing and plant population in a temperate environment. In the present study we have tested the model for its ability to predict vegetative and reproductive development, canopy growth, light interception, dry matter production, pod and seed yields of groundnut (cv. Robut 33-1) as influenced by differences in row spacing and plant population in a semi-arid tropical environment. Data obtained from the 1987 and 1991 rainy season experiments on Robut 33-1 were used to calibrate this cultivar for its growth habit (RWIDTH and RHIGH) parameters. Other cultivar-specific (genetic) parameters had been calibrated earlier by Singh et al. (1994) using data from multilocation experiments. RWIDTH was set at 0.55 and RHIGH at 1.0 so that the total dry matter production predicted by the model matched the actual data in 1987 and 1991. Soil parameters for this site were determined using the data obtained from the calibration experiments (Singh et al., 1994). Data obtained from the 1992 season experiment formed an independent data set to validate the model. Both the genetic and soil parameters once estimated were fixed so that the accuracy of the model could be determined against the independent data.

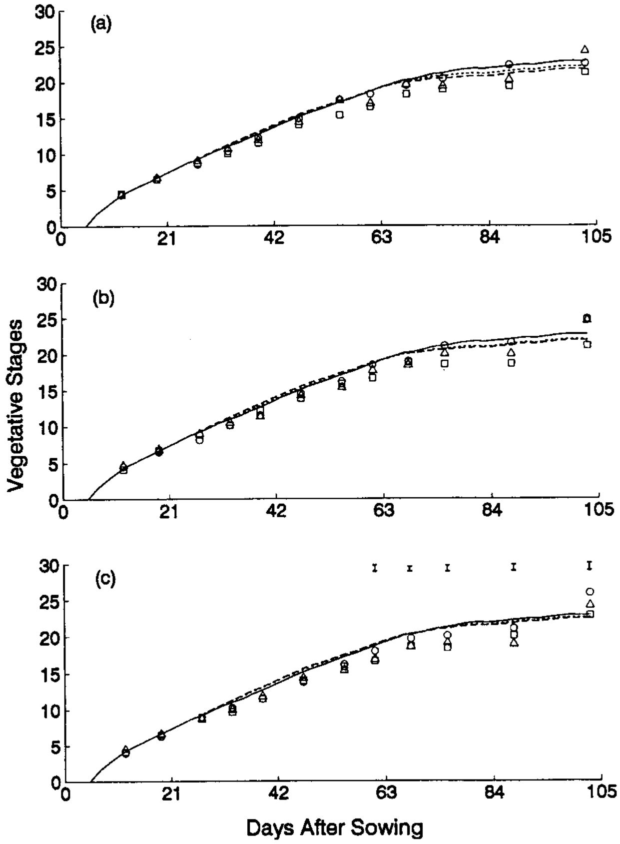

Fig. 1. Simulated (lines) and observed (data points) progression of vegetative stages in (a) 20-cm, (b) 30-cm, and (c) 60-cm row spacings at 10 (○, solid line), 20 (△, dotted line), and 40 (□, broken line) plants/m^2 plant population levels during the 1992 rainy season. Vertical bars represent twice the standard error of treatment means.

4.1. Crop development

Vegetative development was not significantly influenced by plant population and row-spacing treatments, except during the pod-filling period when vegetative development was slightly delayed at high plant density (40 plants/m^2) in all row spacings (Fig. 1), but this effect was not statistically significant. This delay in development could be due to mild water deficit or greater competition for light among plants at high plant densities. Predicted vegetative development by the model at various times during the season for all treatments was close to the observed data and was within the variability normally observed in the field for this trait. The model also simulated the delay in develop-

Table 1
Simulated (S) and simulated minus observed (S–O) days from sowing to flowering (R_1), beginning of peg growth (R_2), beginning of pod growth (R_3), and beginning of seed growth (R_5) of groundnut cv. Robut 33-1 during the 1992 post-rainy season at Patancheru

Row spacing (cm)	Plant population (plants/m^2)	R_1		R_2		R_3		R_5	
		S	S−O	S	S−O	S	S−O	S	S−O
20	10	29	1	38	2	44	2	55	−3
	20	29	1	37	1	44	1	54	−4
	40	29	0	37	1	44	1	54	−4
30	10	29	1	38	2	45	2	55	−3
	20	29	3	37	1	44	1	54	−4
	40	29	2	37	1	44	1	54	−4
60	10	29	4	38	2	45	2	55	−3
	20	29	2	37	1	44	1	54	−4
	40	29	1	37	1	44	1	54	−4
Root mean square error			2.0		1.4		1.4		3.7

ment as observed at high plant densities. Reproductive development was not influenced by the treatments and the model predicted the occurrence of flowering, pegging, beginning of pod growth, and beginning of seed growth within ±4 days of observed values (Table 1). The crop reached physiological maturity (80% of pods mature) 103 days after sowing (DAS) and was harvested on 110 DAS. Model simulations of crop growth were terminated on DAS 103 because late leaf spot and rust caused yield reductions after this date.

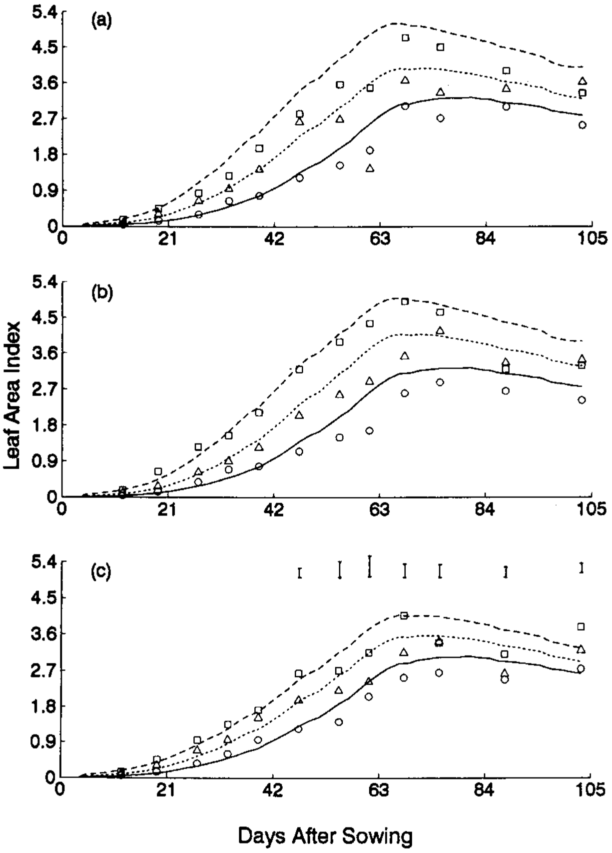

Fig. 2. Simulated and observed dynamics of leaf area index at three plant population levels in (a) 20-cm, (b) 30-cm, and (c) 60-cm row spacings during the 1992 rainy season. Symbols as in Fig. 1.

4.2. Canopy development

The main influence of row spacing and plant population was on the rate of canopy development and the maximum leaf area index (LAI) achieved during the season. Canopy development was slowest at the lowest plant population in all row spacings. Leaf area index was highest at 40 plants/m^2 population in the 30-cm row spacing and lowest in the 60-cm row spacing at 10 plants/m^2 (Fig. 2). The model predicted the increase in LAI and the decay due to senescence accurately in all treatments. The maximum LAI in the majority of treatments were slightly overestimated, but there was a significant correlation ($r^2=0.95$) between observed and simulated values. This overestimation in some treatments is attributed to the incidence of diseases and pests during the season which influenced foliage growth especially in the low plant population treatments. However, the predicted values in the majority of the cases were within the errors associated with observed data. These results show that the model is capable of predicting canopy development as influenced by row spacing and plant population.

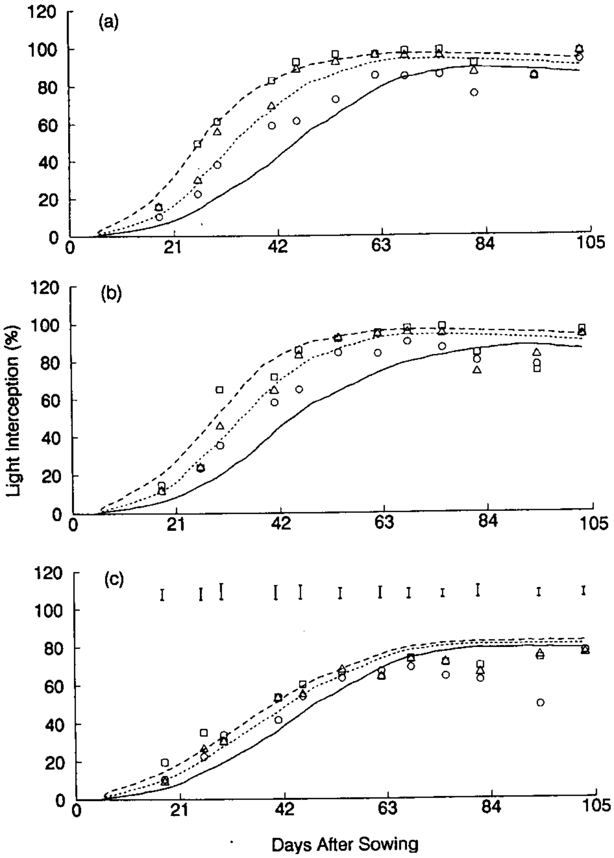

Fig. 3. Simulated and observed dynamics of midday light interception (total solar) at three plant population levels in (a) 20-cm, (b) 30-cm, and (c) 60-cm row spacings during the 1992 rainy season. Symbols as in Fig. 1.

4.3. *Light interception*

Row spacing and plant population had significant influence on the amount of light intercepted by the crop canopy (Fig. 3). Percent light interception was smallest in the 60-cm row spacing at all plant population levels. At 40 plants/m^2, maximum light interception observed during the season did not exceed 80% in 60-cm row spacing, while it exceeded 90% in other row spacings. Among the plant population levels, 10 plants/m^2 had lower light interception than 20 and 40 plants/m^2, especially during the early phases of crop growth. Percent light interception was not significantly different between 20 and 40 plants/m^2. The model predicted light interception by the crop most accurately in all row spacings at the highest plant population. At the lowest plant population (10 plants/m^2), the model underestimated light interception in all row spacings. This may be attributed either to a more decumbent growth habit of single plants at very low plant population or to the method of measuring light interception (positioning of quantum sensor beneath the crop) being inappropriate at very low plant population when the canopy cover is small.

4.4. *Total dry matter accumulation, pod and seed yields*

Significant differences were observed among treatments in the rate of total dry matter production by the crop (Fig. 4). Both the rate of dry matter production during the season and total dry matter produced at harvest were highest at the greatest plant population. The rate of dry matter production prior to 50 days after sowing (DAS), as indicated by the slope of the growth curve, was progressively lower with smaller plant population at all row spacings. After 50 DAS, the rates became similar indicating similar light interception at all plant population levels in a given row spacing. The model predicted the patterns of dry matter accumula-

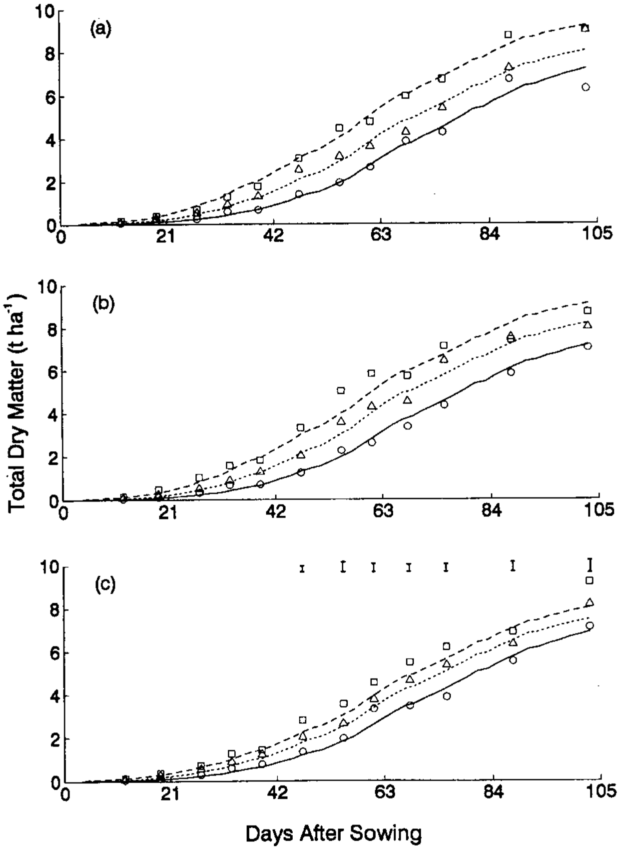

Fig. 4. Simulated and observed changes in total dry matter accumulation at three plant population levels in (a) 20-cm, (b) 30-cm, and (c) 60-cm row spacings during the 1992 rainy season. Symbols as in Fig. 1.

Table 2

Observed (O) and simulated (S) dry matter accumulation in pods at various times during the season and pod yield (t ha^{-1}) at final harvest in various treatments during the 1992 rainy season

Days after sowing	Plant population (plants m^{-2})						SE±
	10		20		40		
	O	S	O	S	O	S	
20-cm row spacing							
61	0.17	0.24	0.41	0.38	0.37	0.49	0.033
75	1.13	1.07	1.33	1.45	1.84	1.77	0.051
88	2.44	2.43	2.53	2.73	3.82	3.31	0.094
103	2.67	3.33	3.80	3.80	4.18	4.12	0.124
110[a]	2.80	–	3.50	–	4.20	–	0.200
30-cm row spacing							
61	0.15	0.25	0.34	0.40	0.55	0.49	0.033
75	1.05	1.10	1.88	1.51	2.10	1.74	0.051
88	2.13	2.21	2.79	2.99	3.13	3.17	0.094
103	3.43	3.30	3.68	3.80	4.35	4.09	0.124
110[a]	2.60	–	3.40	–	4.10	–	0.200
60-cm row spacing							
61	0.24	0.22	0.41	0.32	0.51	0.37	0.033
75	0.91	1.00	1.60	1.26	2.34	1.39	0.051
88	1.94	2.10	2.87	2.64	2.45	2.82	0.094
103	3.13	3.24	4.06	3.57	3.90	3.80	0.124
110[a]	2.30	–	3.00	–	3.80	–	0.200

[a] Final harvest from the 19.2-m^2 area.

tion in all treatments accurately during the season. Partitioning of dry matter to pods as influenced by plant population and row spacing followed a trend similar to total dry matter production (Table 2). Predicted dry matter accumulation in pods on most sampling dates up to physiological maturity (80% mature pods on DAS 103) was within 15% of the observed values. The model also predicted seed yield formation with similar accuracy to pod yield in various treatments (data not presented).

The crop showed some effect of late leaf spot and rust during the later part of the pod-filling period caused by loss of green leaf area and therefore a loss in total dry matter and pod yields. This effect was further magnified by rainfall received near maturity of the crop which caused further loss in yield. The data have been presented for the pod yields obtained at final harvest on DAS 110 from the large area (19.2 m^2) as well as for the yields obtained at physiological maturity (DAS 103) from the small area (0.75 m^2) when the crop was relatively disease free (Table 2). Comparison of these two data sets shows that disease caused a greater reduction in yield at low than at high plant population.

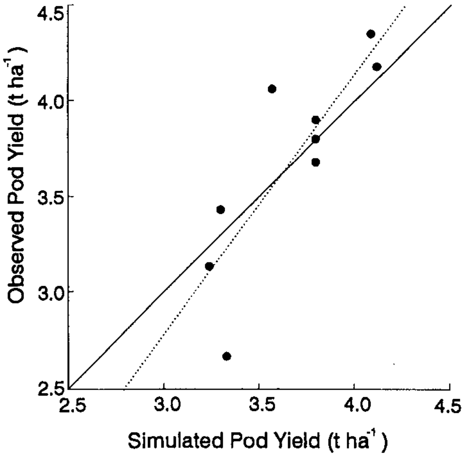

Fig. 5. Relation between observed and simulated pod yield at physiological maturity. $y = -1.10(\pm 1.434) + 1.29(\pm 0.385)x$, $r^2 = 0.61$, rse = 0.355. Broken line: regression line; solid line: 1:1 line.

Pod yields at final harvest increased significantly with increase in plant population from 10 to 20 plants/m^2 at all row spacings, and highest pod yields were obtained in the 20-cm and 30-cm row spacings at 40 plants/m^2. Pod yields did not differ between row spacings at given plant population, except that yields in the 60-cm row spacing, which were significantly smaller than those in the 20-cm row spacing at 10 and 20 plants/m^2. These results agree with those obtained by Bell et al. (1987, 1991), Jaaffar and Gardner (1988), and Gardner and Auma (1989) who found that as the sowing patterns approach equidistant spacings pod and seed yields increase. Simulated pod yields were significantly correlated ($r^2 = 0.61$) with the observed yields on DAS 103 (Fig. 5). The intercept of the regression line did not differ from zero and the slope did not differ from 1.0 at 5% level of probability, indicating that the model predicted pod yields without any bias.

5. Conclusions

It is concluded from this study that the hedgerow version of the groundnut model PNUTGRO accurately predicted crop phenology, canopy development, and accumulation of total dry matter, pod and seed yields of groundnut as influenced by row spacing and plant population under adequate moisture availability. Therefore the model can be used to optimize row spacing and plant population requirements of groundnut in different environments.

Acknowledgements

We thank M/s S. Ramakrishna, R. Mukunda Reddy, Y.V. Srirama and B.N. Reddy for their assistance in conducting field experiments and data management. We also thank Mr. K.N.V. Satyanarayana for typing this manuscript and the anonymous referees for their comments and suggestions to improve this manuscript. Submitted as Journal Article No. 1611 by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

References

Bell, M.J., Muchow, R.C. and Wilson, G.L., 1987. The effect of plant population on peanuts (*Arachis hypogaea*) in a monsoonal tropical environment. Field Crops Res., 17: 91–107.

Bell, M.J., Harch, G. and Wright, G.C., 1991. Plant population studies on peanut (*Arachis hypogaea* L.) in sub-tropical Australia: 1. Growth under fully irrigated conditions. Aust. J. Exp. Agric., 31: 535–543.

Boote, K.J., 1982. Growth stages of peanut (*Arachis hypogaea* L.). Peanut Sci., 9: 35–40.

Boote, K.J. and Loomis, R.S., 1991. The prediction of canopy assimilation. In: K.J. Boote and R.S. Loomis (Editors), Modeling crop photosynthesis: From biochemistry to canopy. CSSA Special Publication no. 19. American Society of Agronomy and Crop Science Society of America, Medison, WI, pp. 109–140.

Boote, K.J., Jones, J.W., Hoogenboom, G. and Wilkerson, G.G., 1987. PNUTGRO v1.0, Peanut crop growth and yield model. Technical documentation. Department of Agronomy and Agricultural Engineering, University of Florida, Gainesville, FL, 121 pp.

Boote, K.J., Bourgeois, G. and Goudriaan, J., 1988. Light interception and photosynthesis of incomplete hedgerow canopies of soybean and peanut. Agron. Abstr., 1988: 105.

Boote, K.J., Jones, J.W. and Hoogenboom, G., 1989. Simulating crop growth and photosynthesis response to row-spacing. Agron. Abstr., 1989: 11.

Boote, K.J. Jones, J.W. and Singh, P., 1992. Modeling growth and yield of groundnut. In: S.N. Nigam (Editor), Groundnut – a Global Perspective. Proceedings of an International Workshop, ICRISAT Center, Patancheru, India, 25–29 November 1991. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India, pp. 331–343.

Gardner, F.P. and Auma, E.P., 1989. Canopy structure, light interception, and yield and market quality of peanut genotypes as influenced by planting pattern and planting date. Field Crops Res., 20: 13–29.

Gijzen, H. and Goudriaan, J., 1989. A flexible and explanatory model of light distribution and photosynthesis in row crops. Agric. For. Meteorol., 48: 1–20.

Holliday, R., 1960. Plant population and crop yield. Nature, London, 186: 22.

IBSNAT (International Benchmark Soils Network for Agrotechnology Transfer), 1989. Decision Support System for Agrotechnology Transfer (DSSAT), v2.1. Documentation of IBSNAT crop model minimum data set entry and retrieval. IBSNAT Project, Department of Agronomy and Soil Science, University of Hawaii, Honolulu, HI.

Jaaffar, Z. and Gardner, F.P., 1988. Canopy development, yield, and market quality in peanut as affected by genotype and planting pattern. Crop Sci., 28: 299–305.

Singh, P., Boote, K.J., Rao, A.Y., Iruthayaraj, M.R., Shekh, A.M., Hundal, S.S., Narang, R.S. and Singh, P., 1994. Evaluation of the groundnut model PNUTGRO for crop response to water availability, sowing dates, and seasons. Field Crops Res., 39: 147–162.

Willey, R.W. and Heath, S.B., 1969. The quantitative relationship between plant population and crop yield. Adv. Agron., 21: 281–321.

Wilkerson, G.G., Jones, J.W., Boote, K.J., Ingram, K.T. and Mishoe, J.W., 1983. Modeling soybean growth for crop management. Trans. ASAE, 26: 63–73.