On-Farm Testing of the PNUTGRO Crop Growth Model in Florida[1]

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ABSTRACT

PNUTGRO is a peanut crop growth simulation model which calculates crop carbon, nitrogen and water balances at the process level. An on-farm evaluation of PNUTGRO v1.02 was conducted at 15 field sites in two Florida counties during the 1990 and 1991 cropping seasons. Independent crop and soil data sets were collected to evaluate PNUTGRO simulations. The accuracy of the PNUTGRO simulations was affected by year and location. Sites where peanut (*Arachis hypogaea* L.) was grown in rotations following bahiagrass (*Paspalum notatum* Fleuge) (Levy County, 1990) had low disease pressure, high pod yields (5260 kg/ha), and the best model fit (PNUTGRO simulations were within 9% of observed yield data). Sites where peanut followed other row crops often showed high infestation levels of root-knot nematode [*Meloidogyne arenaria* (Neal) Chitwood] or stem rot (*Sclerotium rolfsii* Sacc.) (Jackson County, 1991). This resulted in reduced pod yields (3260 kg/ha) and poorer model fit (PNUTGRO simulations were 44% above observed yields). PNUTGRO correctly predicted relative yield decreases due to drought. Overall, PNUTGRO v1.02 appears to be most useful as a predictor of optimal peanut yield for specific cultivars under given soil and weather conditions. Inclusion of pest and disease damage functions would improve model accuracy for farms where biotic stress reduces potential peanut yield.

Key Words: *Arachis hypogaea*, cropping system, peanut.

Peanut (*Arachis hypogaea* L.) yields have fluctuated greatly in the southeastern (SE) U.S. during the last two decades due to drought. Average pod yields in the SE region have ranged from 1510 kg/ha in Alabama in 1990 to 2880 kg/ha in Florida in 1996 (USDA, 1991, 1997). Computer growth models may be able to explain the effect of weather conditions on these yield fluctuations (Boote and Jones, 1988; Williams and Boote, 1995). These models also may be used as a management tool for assessment and implementation of optimal management strategies.

The PNUTGRO peanut crop growth simulation model is a physiologically based model which considers crop carbon, nitrogen, and water balances at the process level. Daily canopy photosynthesis, respiration, growth, phenology, and partitioning are predicted based on weather, soil, varietal, and management inputs (Boote *et al.*, 1986, 1989b). The PNUTGRO crop growth model used in this study (v 1.02) does not include factors related to soil fertility or biotic stress factors such as diseases, weeds, insects, or nematodes.

Crop simulation models such as PNUTGRO can serve as aids in agricultural research or crop management (Whisler *et al.*, 1986). However, these models must be validated under field conditions using data sets independent of development or calibration (Burk, 1986). This testing requires growth analysis throughout the crop growing season; final yield data alone are inadequate for model validation (Acock and Acock, 1991). Model evaluation can be based on regression analysis of simulated and observed values at different points during the growing season (Huda, 1988).

Crop growth simulation models need to be calibrated and validated with field data over a wide range of environmental conditions to improve model performance in different agroecosystems. The PNUTGRO model first was evaluated on peanut farms in north Florida in 1988 (Boote *et al.*, 1989a). The model tended to overpredict peanut growth and yield on farms with disease and nematode problems. A version of the PNUTGRO model calibrated using the 1988 north Florida data predicted growth and yield reasonably well in the 1989 growing season.

The objectives of this study were to (a) evaluate PNUTGRO model v 1.02 under actual farm conditions in two Florida counties with differing agroecologies and cropping histories, (b) determine the utility of PNUTGRO to farmers and extension agents, and (c) identify areas for model improvement. In order to achieve this, independent crop, weather and soil data sets from 15 Florida peanut fields were collected and compared to PNUTGRO-simulated values.

Materials and Methods

Site Selection and Cropping History. Field testing of the PNUTGRO model was conducted in Jackson and Levy counties, FL during the 1990 and 1991 growing seasons. A total of 15 field sites were used during this 2-yr study. In 1990, four sites were selected in Jackson County and four in Levy County, while in 1991 there were four field sites in Jackson County and three in Levy County. Table 1 identifies the field sites and shows the cultivar, irrigation, and soil subgroup at each site. The CR farm in Jackson County in 1990 and 1991 used a center pivot irrigation system. Sites were selected under the pivot and in a dry corner of the field, providing rainfed (CR-R) and irrigated (CR-I) treatments in one field. The MO rainfed and irrigated sites in Jackson County and all the Levy County sites were in different fields.

The cropping system followed at the Levy County sites used peanut crop rotations with livestock-grazed bahiagrass. Bahiagrass rotations have been shown to reduce nematode populations (Rodriquez-Kabana *et al.*, 1988) and leaf spot infection rates (Jackson, 1981) in subsequent peanut crops. PNUTGRO v 1.02 does not presently account for soil fertility factors, but soil fertility was not considered a limiting growth

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Table 1. Field sites in Levy and Jackson counties, FL in 1990 and 1991.

Year	County	Site	Cultivar	Irrigation	Soil subgroup
1990	Levy	BR	Florunner	Yes	Grossarenic Paleudults
		GR	Florunner	Yes	Grossarenic Paleudults
		LO	Sunrunner	No	Arenic Hapludalfs
		SA	Sunrunner	Yes	Typic Quartzipsamments
	Jackson	CR-R	Agritech-127	No	Grossarenic Paleudults
		CR-I	Agritech-127	Yes	Grossarenic Paleudults
		MO-R	Florunner	No	Typic Paleudults
		MO-I	Florunner	Yes	Typic Paleudults
1991	Levy	GR	Marc I	No	Grossarenic Paleudults
		LO	Florunner	No	Arenic Hapludalfs
		SA	Sunrunner	No	Typic Quartzipsamments
	Jackson	CR-R	Agritech-127	No	Grossarenic Paleudults
		CR-I	Agritech-127	Yes	Grossarenic Paleudults
		MO-R	Florunner	No	Typic Paleudults
		MO-I	Florunner	Yes	Typic Paleudults

factor in this experiment as nutrient deficiencies did not limit peanut growth on-farm.

Bahiagrass rotations with livestock grazing were not practiced at the four field sites in Jackson County. The CR-R and CR-I sites had peanut in 1990 following soybean (*Glycine max* L. Merrill) in 1989 and a soybean-wheat (*Triticum aestivum* L.) rotation in 1988. The MO-I site had peanut following wheat, corn (*Zea mays* L.), and cotton (*Gossypium hirsutum* L.) in the previous 2 yr. The MO-R field had been in bermudagrass (*Cynodon dactylon* Harlan and de Wet) since 1982.

Four Jackson County sites were chosen for sampling in 1991. The CR-R and CR-I sites were planted on a field adjacent to the 1990 site. This field had been in sorghum (*Sorghum bicolor* L. Moench) in 1990, soybean in 1989, and peanut in 1988. The MO-R crop was planted at the same location as in 1990. The MO-I site was shifted to a field following cotton in 1990, corn in 1989, and a wheat/millet [*Pennisetum glaucum* (L.) R. Br.] crop sequence in 1988. The soil types and fertility levels were similar to fields used in 1990.

Soil Water Determination. Gravimetric soil water content (G, %) was sampled in two replications per site every 3 wk in Levy County farms and every 4 wk in Jackson County farms. Soil samples were taken from 0-15, 15-30, 30-45, 45-60, 60-90, and 90-120 cm depths. Bulk density values (D_b, Mg/m^3) for the six soil layers at each site were obtained using Soil Conservation Service maps. Volumetric water content (θ, %) was then calculated as:

$$\theta = G * D_b \quad \text{[Eq. 1]}$$

Weather Data Collection. In order to simulate peanut growth and yield, the PNUTGRO model requires several weather inputs –solar radiation, minimum and maximum daily air temperature, and daily rainfall and irrigation. LICOR LI-1200 (LI-COR, Lincoln, NE) weather stations were placed in each county to obtain daily solar radiation and minimum and maximum air temperatures. Weather stations were located at the MO-R farm in Jackson County and the SA farm in Levy County. In addition, a LI-1000 data logger was installed to record weather data at the GR farm in Levy County. Automated tipping bucket rain gauges were installed at every field site to record rainfall and/or irrigation in each field. Solar radiation and air temperatures from weather stations in each county were combined with rainfall and irrigation data obtained from each field site to create weather files for each experimental site (Table 2).

Table 2. Seasonal weather data for field sites in Levy and Jackson counties, FL in 1990 and 1991.

Year	County	Site	Precipitation and/or irrigation	Avg solar radiation	Avg daily temp.[a]
			mm	MJ/m²/d	C
1990	Levy	GR	583	21.0	25.9
		BR	773		
		SA	783		
		LO	645		
	Jackson	MO-R	421	22.3	26.1
		MO-I	----[b]		
		CR-R	407		
		CR-I	----[b]		
1991	Levy	GR	1184	19.2	27.0
		SA	875	19.3	26.2
		LO	626		
	Jackson	MO-R	808	19.1	26.6
		MO-I	----[b]		
		CR-R	675		
		CR-I	732		

[a]Calculated as seasonal average of daily (T_{max} + T_{min})/2.

[b]---- Indicates missing data due to rain gauge malfunction.

Plant Growth and Harvest Sampling. In each field, four plots of 66.8 m^2 each were established within a uniform area of each field. Each plot served as a replicate for observed growth and yield measurements. Plant growth measurements were taken every 3 wk at Levy County sites and every 4 wk at Jackson County sites throughout the growing season. Plant sampling commenced at 25-35 d after planting and continued through harvest. One meter of row (0.914 m^2 area) was sampled from each of the four replications. Sampled areas were well bordered by adjacent rows and in-row plants prior to sampling. Plant height, plant number, and canopy width were measured in the field. Reproductive stages were determined for all plants in the sample, and total biomass dry weight was determined after oven-drying at 70 C for 3 d. A three-plant subsample of representative plants within each replication was used to calculate the following growth data: vegetative stage, specific leaf area, leaf area, stem dry weight, leaf dry weight, number of pegging sites, number of pods, seed number, and seed dry weight.

The fractional distribution of dry matter among plant parts in the three-plant subsample was multiplied by the total dry matter of the larger (0.914 m^2) total biomass sample to compute mass of various plant parts. This technique assumes that the ratio of leaf (or stem, pod, etc.) weight to total biomass is similar for neighboring plants of the same age and genotype (Pixley *et al.*, 1990).

A final harvest sample of 8.94 m^2 per plot was taken as close as possible to the grower harvest date. Total pod and seed dry weight from this sample were used to compute observed final yield measurements.

Input File Generation. The PNUTGRO crop growth model predicts peanut growth and yield in response to soil, weather, genetic and management inputs for a specific location and growing season. PNUTGRO version 1.02 was used; this version had been tested in north Florida in 1988 (Boote *et al.*, 1989a) and found to overestimate peanut growth on farms with disease and nematode problems. The genetics file used in this study was calibrated to 1988 on-farm studies in Jackson County and shown to work reasonably well in the 1989 season in Jackson County. The genetic coefficients, which include life-cycle phase durations, are defined in Boote *et al.* (1989b). The main changes made to the genetics file during this calibration to 1988 data were to reduce leaf photosynthesis by 11% to reduce dry matter accumulation, and reduce length of Florunner reproductive period by 10% to shorten the life cycle to match the observed data of 1988. Specific leaf area and trifoliate production rate were reduced also by 9 and 3%, respectively.

Soil files were created using Soil Conservation Service (SCS) data and maps for each field. The IBSNAT soil retrieval program (Anon., 1990) was used to calculate lower limits and drained upper limits of extractable soil water based on percent sand, silt, clay, and organic carbon from the SCS maps at each site. Weather files were compiled with weather station and rain gauge data.

Model Evaluation. Observed plant growth and yield data on peanut growth stage, leaf area index (LAI), and dry matter weights of seeds, pods, leaves, and stems throughout the season, as well as pod yield at final harvest, were compared with PNUTGRO-simulated values. The predictive capability of PNUTGRO under actual farm conditions was then evaluated by comparing field-observed growth and yield data to PNUTGRO-simulated values.

The null hypothesis tested in this study was that PNUTGRO v 1.02 accounts for weather, soil, and cultural practices affecting on-farm peanut growth and yield. Statistical comparison of observed data to PNUTGRO simulations was performed in two ways. For time-series data presented in figures and final yield data (Tables 3 and 4), standard error bars were included to indicate the variability associated with observed means (note that there can be no statistical measure of variability of the PNUTGRO simulation line as the simulation is not replicated for a given site). If the simulation falls within the standard error of the observed data, then the model is considered statistically robust. Note that R_2 is not an appropriate statistic for the figures since we are not interested in the goodness of fit of the data to the "best-fit" line, but to the simulation line.

Standard errors (Sy) for the plant growth and soil water sampling means were calculated using the following formula:

$$S_y = s \ / \sqrt{n} \qquad \text{[Eq. 2]}$$

where s = standard deviation and n is the number of samples. The standard error is expressed as a bar ($y \pm S_y$) centered over the field-observed values on PNUTGRO simulation graphs.

To evaluate model fit across sites (Table 5), a simple linear regression was performed following the procedure of Huda (1988). An R^2 value and slope were calculated from a linear regression of observed (x) vs. simulated (y) values. The closer R^2 and slope are to 1.0, the better the fit of the model. A slope < 1.0 indicates that the model underestimates, while a slope > 1.0 indicates an overestimation of the model.

In this manuscript there was not an attempt to show tables and figures for all the data collected. Rather, figures and tables are included to illustrate representative trends for a given county and/or year.

Results and Discusison

1990, Levy County. Levy County farms received sufficient combined rainfall and irrigation (Table 2) to exceed the 500-600 mm of well-distributed water needed for adequate peanut growth and development (Boote *et al.*, 1982). The PNUTGRO model tended to overestimate volumetric soil water content when θ fell below 5%

Table 3. Field-observed (OBS) vs. PNUTGRO-simulated (SIM) growth and yield data for Levy and Jackson counties, FL field sites in 1990.

		Total crop biomass at R8[a]			Pod yield		
County	Site	OBS	S_y[b]	SIM	OBS	S_y	SIM
		------------kg/ha------------			--------kg/ha--------		
Levy	SA	11850	2001	10890	5680	949	5470
	LO	8530	1170	11620	5010	502	5480
	BR	12070	1056	11270	5370	307	4660
	GR	12190	1282	10970	4980	475	4520
Jackson	CR-R	7210	1167	5390	1490	251	2270
	CR-I	9740	1445	11130	3920	279	5500
	MO-R	8370	1278	7740	3610	475	2820
	MO-I	12240	1111	12210	5030	223	5200

[a]R8 is the harvest maturity growth stage.
[b]S_y = standard error of the observed mean.

Table 4. Field-observed (OBS) vs. PNUTGRO-simulated (SIM) growth and yield data and root-knot nematode levels at Levy and Jackson counties, FL sites in 1991.

County	Site	Total crop biomass at R8[a]			Pod yield			Root-knot nematodes	
		OBS	S_y[b]	SIM	OBS	S_y	SIM	Roots	Soil
		------------kg/ha ------------			------------kg/ha ------------			no./g	no./cm³
Levy	SA	8760	2109	10490	4620	1026	5120	0	0
	LO	8470	179	10800	3800	538	4450	18.2[c]	2.6[c]
	GR	7790	403	9710	3780	272	4790	0	1.0
Jackson	MO-R	9630	718	11200	3170	196	4440	9.7[c]	4.3[c]
	MO-I	9100	1032	11210	3840	245	4590	17.8[c]	4.7[c]
	CR-R	7850	853	9640	3520	269	4570	49.5[c]	1.3[c]
	CR-I	5980	1121	9590	2500	342	4640	375.5[c]	17.6[c]

[a]R8 is the harvest maturity growth stage.
[b]S_y = standard error of the observed mean.
[c]Indicates nematodes levels high enough to cause serious crop injury.

Table 5. Linear regression slopes and R^2 values of field observed vs. PNUTGRO-simulated plant growth characteristics.

County	Year	LAI		Stem wt.		Leaf wt.		Total crop wt.		Pod wt.	
		R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope	R^2	Slope
Levy	1990	0.74	1.01	0.87	0.80	0.86	1.03	0.93	0.92	0.93	0.88
Jackson	1990	0.88	1.20	0.94	0.91	0.88	1.06	0.97	0.97	0.97	0.95
Avg	1990	0.81	1.11	0.91	0.86	0.87	1.05	0.95	0.95	0.95	0.92
Levy	1991	0.65	1.36	0.73	1.08	0.67	1.11	0.91	1.16	0.96	1.03
Jackson	1991	0.71	1.36	0.83	0.91	0.85	1.34	0.93	1.15	0.96	1.16
Avg	1991	0.68	1.36	0.78	1.00	0.76	1.23	0.92	1.16	0.96	1.10
Avg	Both	0.75	1.24	0.85	0.93	0.82	1.14	0.94	1.06	0.96	1.01

(data not shown) at the LO and SA sites, but predictions followed the general trend of wetting and drying cycles observed in the individual fields.

Peanut growth and yield in Levy County in 1990 generally attained the growth and yield potential predicted by PNUTGRO. Table 3 shows observed versus simulated growth and yield values taken at pod harvest for the SA, LO, BR, and GR sites in 1990. Both total crop weight and pod weight showed close agreement to model simulations throughout the season at one of the sites (Fig. 1), as did partitioning of assimilate to pods. Overall, peanut growth and yield predictions were accurate for Levy County in 1990 and were generally within one standard error of observed values. PNUTGRO-simulated pod yields differed by an average of only 9% from observed yields. Total crop weights at harvest maturity (R8 growth stage of peanut) differed by 15%. PNUTGRO seemed to predict peanut growth and yield reasonably well following long-term bahiagrass crop rotations with no noticeable pest and disease pressures.

1990, Jackson County. Rainfall was a serious con-

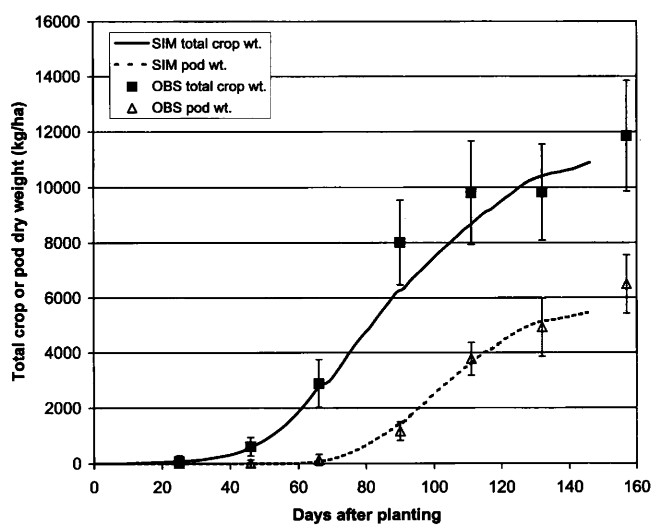

Fig. 1. Measured (points) and PNUTGRO-simulated (lines) pod and total crop weights at the SA site in Levy County in 1990.

straint to growth in rainfed Jackson County fields in 1990. Cumulative rainfall at the CR-R and MO-R fields were 407 and 421 mm, respectively (Table 2). Unfortunately, the rain gauges under the center pivot malfunctioned during midseason at the MO-I and CR-I sites. Thus, it was necessary to assume for the PNUTGRO simulation that the plants in these fields were not under water stress. This assumption was corroborated by field observation. When serious wilting was observed in the rainfed MO-R and CR-R plots, no stress was observed in the MO-I and CR-I sites. Without this assumption, the model would have predicted severe water stress similar to that observed in the MO-R and CR-R plots. Drought at the CR-R site caused soil volumetric water content in the upper 30 cm to decrease during drying cycles throughout the growing season (Fig. 2), and there was close agreement of observed values to the PNUTGRO-simulated values. PNUTGRO consistently overestimated volumetric soil water percent at MO-R (data not shown), although the model did follow the general seasonal drying trend.

The drought in 1990 in Jackson County caused large growth and yield differences between the rainfed and irrigated fields on both the CR and MO farms (Table 3). PNUTGRO also responded to these weather effects by simulating drought stress on the rainfed crops where the simulated photosynthesis was decreased by 45% in the MO-R field and 55% at the CR-R site from end of pod addition to physiological maturity.

Table 3 shows observed versus simulated growth and yield values for the Jackson County farms in 1990. Several diseases (leaf spot and white mold) were noted in the CR-I field, which followed 2 yr of soybeans. PNUTGRO overestimated total biomass at maturity by 14% and pod yield by 40% for the CR-I field due to disease pressure for which the model does not account. The CR-R site showed pronounced effects of drought which reduced both growth and pod yield. While the PNUTGRO-simulated yields at the CR-R site were reduced compared to CR-I, PNUTGRO overestimated

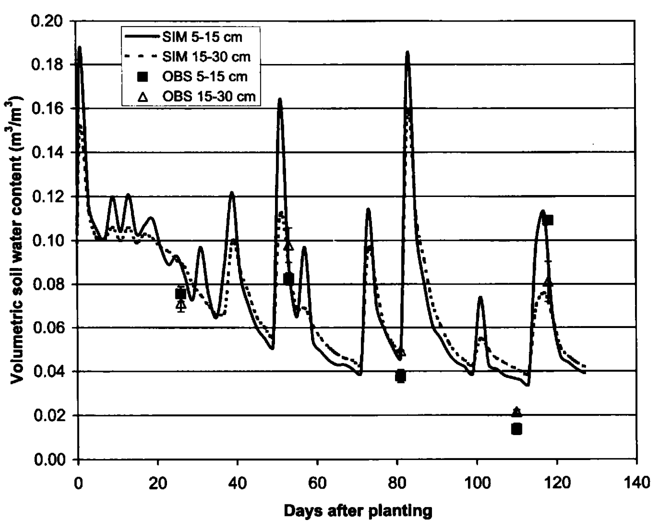

Fig. 2. Measured (points) and PNUTGRO-simulated (lines) volumetric soil water content from 5-15- and 15-30-cm soil layers at the CR-R site in Jackson County in 1990.

fractional partitioning to pods (harvest index was overestimated by 0.21). Final pod yield estimates for the CR-R field were 52% higher than observed.

Florunner was grown at both the irrigated and rainfed sites of the MO farm. PNUTGRO-predicted total crop growth and seasonal partitioning of assimilate to pods closely matched observed values at the MO-I site (Fig. 3). PNUTGRO-estimated final biomass and pod yield was within 0.3 and 3.4% of observed values (Table 3). The growth and yield of peanut on the MO-R site was remarkably good considering the severity of drought stress. PNUTGRO underestimated pod and total crop growth beginning at the R6 stage. Final biomass and yield were underestimated by 8 and 22%, respectively.

Overall, the yield predictions by PNUTGRO in 1990

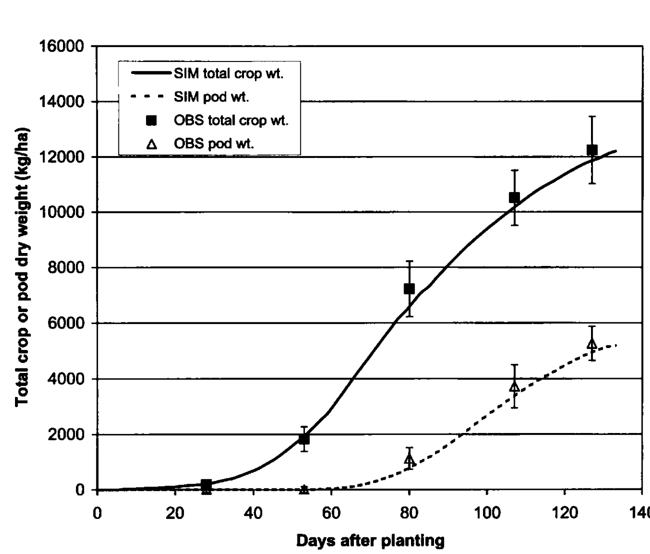

Fig. 3. Measured (points) and PNUTGRO-simulated (lines) pod and total crop weights at the MO-I site in Jackson County in 1990.

were more accurate in Levy County than in Jackson County. The bahiagrass rotation followed in Levy County allowed peanut to reach its climatic yield potential. The row crop rotations used in three of the Jackson County fields resulted most likely in higher incidence of pests (not measured in 1990) compared with the bahiagrass rotations of Levy County, causing growth limitations unaccounted for in this version of PNUTGRO. However, PNUTGRO v 1.02 did predict the relative decrease in pod yield due to drought in Jackson County. This is in agreement with previous simulation results under drought conditions using PNUTGRO v 1.0 (Williams and Boote, 1995).

1991, Levy County. Growers in Levy County in 1991 followed the same cropping system of bahiagrass rotations with peanut described previously. However, the climatic conditions in 1991 were more humid than 1990, and the seasonal solar radiation in 1991 was 8.3% less than 1990 (Table 2). However, the average daily temperature was higher due to higher minimum temperatures. All three Levy County farms received more than adequate rainfall for peanut growth, with an average of 895 mm per site (200 mm greater than in 1990). Volumetric soil water contents were higher in 1991 than in 1990, with PNUTGRO-simulated soil water values closely following observed seasonal trends at the GR site (Fig. 4).

PNUTGRO simulations of crop growth and yield in Levy County in 1991 were not as accurate as they were in 1990 (Table 4). The GR farm used the cultivar Marc I in 1991. This cultivar is early maturing but susceptible to leaf spot (*Cercospora* spp.) and rust (*Puccinia arachidis* Speg.). The GR site received 1184 mm of precipitation with a 27.0 C average daily temperature, which are favorable moisture and temperature conditions for leaf spot and rust infection (Porter *et al.*, 1982; Subrahmanyam *et al.*, 1984) and leaf spot disease was notably observed as a likely limitation to yield in this field.

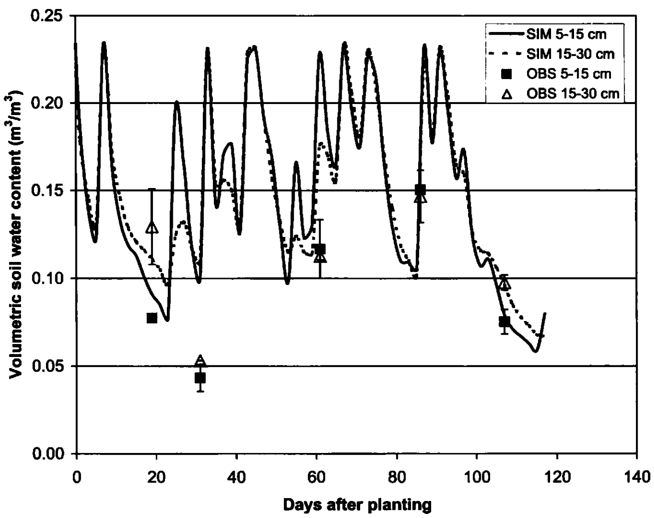

Fig. 4. Measured (points) and PNUTGRO-simulated (lines) volumetric soil water content from 5-15- and 15-30-cm soil layers at the GR site in Levy County in 1991.

PNUTGRO predicted LAI accurately at the GR site until leaf spot and rust infection induced defoliation in mid-July (Fig. 5A). Measured LAI decreased 68% from a maximum of 3.9 at 60 d after planting, while PNUTGRO predicted a maximum LAI of 5.2 at 75 d after planting due to the optimal weather conditions for peanut growth. Similarly, PNUTGRO overestimated total crop weight and pod yield at the end of the season as defoliation occurred at the GR site (Table 4).

Florunner was planted at the LO site in 1991. While leaf spot and rust damage was minimal at the LO site, a nematode assay taken on 19 Aug. revealed root-knot nematode levels high enough to cause serious crop injury (18.2 larvae/g roots). PNUTGRO overestimated plant growth and LAI from the pegging stage through harvest (Fig. 5B), as root-knot nematodes began to limit peanut growth. While growth and yield were reduced at both the GR and LO sites, the observed growth curves were noticeably different. Leaf spot infection caused a dramatic drop in LAI late in the season (Fig. 5A) while nematode infection caused a premature flattening of the linear growth phase (Fig. 5B).

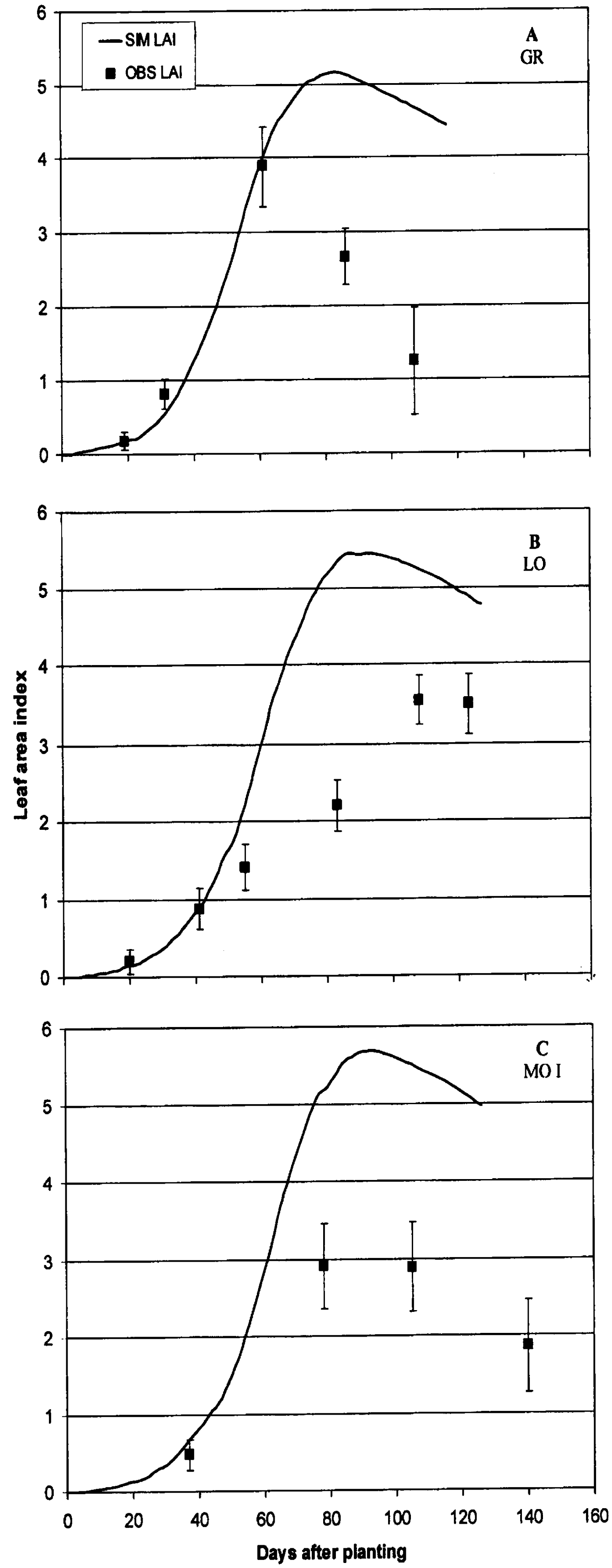

Fig. 5. Measured (points) and PNUTGRO-simulated (line) leaf area index (LAI) at the GR site in Levy County (A), the LO site in Levy County (B), and the MO-I site in Jackson County (C) in 1991.

Overall, peanut growth and yield predictions using PNUTGRO were less accurate in 1991 than in 1990 for Levy County. PNUTGRO overestimated pod yield by an average of 21% (9% in 1990). Similarly, total crop weights at R8 differed by 21% (15% in 1990). The unaccounted growth and yield reduction due to pests and diseases in the warmer, more rainy season led to consistent PNUTGRO overestimates of peanut growth in Levy County in 1991.

1991, Jackson County. Average rainfall in Jackson County was 324 mm greater in 1991 than 1990 (Table 2). Daily solar radiation at the MO-R weather station declined 3.2 $MJ/m^2/d$ from 1990. Average volumetric soil water measurements in 1991 were 53% higher at the CR-R site and 35% higher at the MO-R site than in 1990.

PNUTGRO estimates of crop growth and yield in Jackson County in 1991 were not as accurate as the 1990 simulations (Table 4). Use of row crop rotations combined with the humid weather conditions of 1991 resulted in both root-knot nematode and stem rot infestation at the CR sites, especially in the CR-I field. Table 4 gives root-knot nematode incidence at all 1991 field sites and illustrates pest effects on simulated versus observed pod yield. By harvest maturity, the CR-I site had extremely high root-knot nematode levels on the roots (376 larvae/g) and in the soil (17.6 larvae/cm^3). Interestingly, root-knot nematode levels were negligible on a nematode assay taken on 6 June. Early-season assays showed negligible levels at all sites in 1991, emphasizing the difficulty often encountered in using pre- (or in this case, early) season assays for predictive purposes (Rodriguez-Kabana *et al.*, 1982).

PNUTGRO simulations of total crop weight and pod weight were consistently higher than observed for the CR-I site in 1991 (Table 4). This is consistent with the negative impact of nematode infection. Stem rot infection contributed to rapid decline in LAI as relative humidity increased under the crop canopy at the end of the season (Porter *et al.*, 1982). The cumulative effect of the two diseases led to large PNUTGRO overestimates of final pod yield (86%) and crop biomass at maturity (60%).

The CR-R site also had root-knot nematode and stem rot infections (Table 4), but nematode infection rates were not as severe as on the CR-I plots. Measured LAI was close to PNUTGRO estimates through the R6 stage, but stem rot infections caused a rapid decrease in LAI. PNUTGRO overestimated final pod yield and biomass at maturity by 30 and 23%.

Root-knot nematode levels were high at both MO sites (Table 4). PNUTGRO overestimated LAI (Fig. 5C), total crop and pod weight in the MO-I field beginning at the R3 stage. Measured maximum LAI was only 2.9 in 1991 compared to 5.1 in 1990. PNUTGRO-simulated final pod yield and total crop biomass were overestimated by 20 and 23%.

Overall, PNUTGRO's pod yield predictions were not as accurate in Jackson County in 1991 (44% difference from observed) as they were in 1990 (29%), or as they were in Levy County in 1991 (21%). Higher rainfall in 1991 and row crop rotations led to higher pest and disease incidence in Jackson County. The consistent model overestimates in 1991 indicate pest and disease growth limitations unaccounted for in PNUTGRO v 1.02.

Statistical Evaluation of PNUTGRO Simulations over All Sites. The accuracy of the PNUTGRO model simulations of plant growth and yield varied between years and between locations. In 1990 (Table 3) PNUTGRO simulations of final biomass and pod yield were within one standard error of observed data at six and four sites, respectively. In 1991 (Table 4), PNUTGRO simulations of final biomass and pod yield were within one standard error of observed data at only one site. The R^2 values for observed vs. simulated LAI, stem weight, leaf weight, and total crop weight were lower in 1991 than 1990 for both Levy and Jackson county sites (Table 5). In addition, the slope of the regression line was > 1.0 for LAI, leaf, crop, and pod weights in 1991, indicating consistent PNUTGRO overestimates of these growth parameters.

Summary and Conclusions

PNUTGRO simulations were most accurate when both abiotic and biotic environments at a given site were optimal for peanut production. Biotic stresses that reduced plant growth (e.g., pests and diseases) resulted in poor performance of the model. As the average yield at on-farm sites in a given county decreased from the potential yield, PNUTGRO yield simulations became less accurate. Average yield at the Levy County sites in 1990 was 5260 kg/ha, and PNUTGRO pod yield simulations differed by 9% from observed; whereas average yield in 1991 was 4065 kg/ha (simulations overestimated by 21%). Average yield in Jackson County in 1990 was 3510 kg/ha, and PNUTGRO yield predictions differed by 29% from observed, whereas average yield in Jackson County in 1991 was 3260 kg/ha (simulations overestimated by 44%).

PNUTGRO v 1.02 appears to be most useful as a predictor of optimal peanut yield under given cultivar, soil, weather, and management variables. The model responds adequately to the abiotic growing environment. Levy County farmers growing peanut following long-term bahiagrass rotations, which reduced pest and disease pressures, achieved the yield potential predicted by PNUTGRO in 1990. The same was true for the sole peanut crop grown in Jackson County in 1990 after bermudagrass. Thus, PNUTGRO v 1.02 can be used to identify production potential of different peanut cultivars, as well as to quantify climatic risk associated with peanut production under rainfed conditions in Florida. It is useful also for extension agents in identifying when growers are not achieving climatic potential peanut yields and thus pointing out a yield gap from biotic pests that they may wish to address.

The PNUTGRO model simulations were more accurate in 1990 than in 1991 for both counties. The higher rainfall in 1991 contributed to high pest and disease levels that lowered peanut yields. PNUTGRO did predict the relative peanut yield decrease due to drought in the rainfed fields of Jackson County in 1990.

Accounting for pest and disease effects on peanut growth and yield will improve PNUTGRO predictions under on-farm conditions. Inclusion of damage functions that adjust PNUTGRO growth and yield predictions during the growing season would greatly improve the accuracy of PNUTGRO simulations. It is important for farmers and extension agents to know when climatic potential peanut yield is not being attained due to biotic stresses.

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