SIMULATING COTTON GROWTH IN CONSERVATION TILLAGE SYSTEMS USING THE GOSSYM MODEL

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Abstract

Models with capabilities to simulate plant responses to strategies of sustainable agriculture such as conservation tillage are useful for making management decisions. This study evaluated the cotton (*Gossypium hirsutum* L.) crop simulation model, GOSSYM, for its ability to simulate cotton growth and yield under no-till and mulch-till systems with a winter rye (*Secale cereale* L.) cover crop and poultry litter (PL) as a nitrogen source. The soil is a Decatur silt loam (clayey, kaolinitic thermic, Typic Paleudults) in northern Alabama. Cotton lint yield under no-till was 7 to 24% greater than that under conventional till. Simulated phenology data were closer to measured data in 1997. In 1998, simulated durations to first square and first flower were 7 to 16 days shorter than observed data, while simulated duration to maturity was up to 15 days longer than observed data. The model generally simulated cotton plant height, LAI, and root dry weight well up to the first flower growth stage. Thereafter, simulated data were significantly lower than measured data. Simulated lint yields were 130 to 390 kg ha^{-1} lower than measured lint yields. These relatively lower values simulated by the GOSSYM model can be attributed to its inability to simulate no-till, cover cropping, and PL effects on water conservation. These treatments conserved 10 to 56% more soil moisture compared to conventional till, ammonium nitrate and no cover cropping. To properly simulate the effects of sustainable cotton production practices such as no-till, GOSSYM needs appropriate modifications in the sub-routines dealing with soil moisture availability.

Introduction

Cotton production has been static or declining in the last decade. The main reasons are soil erosion and declining soil organic matter. Conservation tillage systems have been proposed to correct these problems which have been slowly taking hold on cotton producers. Our experiments have shown that no-till and mulch-till with cover cropping and PL as a nitrogen source can reduce soil erosion by water, conserve soil moisture, increase soil organic matter, and improve crop yields (Nyakatawa and Reddy, 2000; Nyakatawa et al., 2000; Nyakatawa et al., 2001). Additional benefits of conservation tillage include reducing machinery, fuel and labor costs and increasing profits primarily due to longer machinery life (Keeling et al., 1989). Using cover crops in cotton production systems can reduce nitrate leaching into groundwater by uptake of excess nutrients from the cotton crop (Kelley et al., 1992). The use of PL as a N source can improve soil tilth, increase soil organic matter, soil water retention and supply nutrients, particularly nitrogen and phosphorus to crops. Poultry litter is available in abundant quantities in most southern states and its disposal is becoming a major environmental problem. Use of PL in crop production such as in the intensive cotton production areas in the Tennessee Valley Region of northern Alabama can alleviate poultry waste disposal concerns in the region.

The GOSSYM model is a physiologically-based material balance model developed to integrate growth, development and agronomic aspects of cotton yield and production (Baker et al., 1983; Staggenborg et al., 1996; Reddy et al., 1997; Hodges et al., 1998). It simulates crop responses to environmental variables such as solar radiation, temperature, rain/irrigation, and wind, as well as variation in soil and cultural practices. The model internally keeps the record of leaf and fruit age and simulates growth and development based on daily temperatures and adjusts the potential rates of growth and development based on the intensity of environmental stresses. Output from the model includes plant height, biomass, growth rate, growth stage of the crop, and the intensity of stress factors such as water and N.

GOSSYM model can provide mid-season management recommendations for cotton irrigation, fertilizer, and harvest aid applications with the help of the expert logic system called COMAX (GOSSYM-COMAX Users Guide, 1993; Norton and Silvertooth, 1998). The model structure and program flow of the GOSSYM model after Hodges et al. (1996) are illustrated in Fig.1. Information on mathematical relationships among weather, soil, and plant responses to physical conditions is organized into packages called subroutines or modules written in FORTRAN language. In Mississippi, Landivar et al. (1983) used GOSSYM to show fruit abscission and yield reduction in okra-leaf cottons. In Lubbock Texas, Staggenborg et al.(1996) found that GOSSYM underestimated cumulative evapotranspiration in a 12 day period. Stevens et al. (1996) concluded that the

GOSSYM model needs modifications for more accurate simulations of N dynamics for it to be used for N management on the Loring silt loam soils of Holly Springs, Mississippi. Norton and Silvertooth (1998) found that the dynamic soil N portion of the GOSSYM model needs further refinement to enable it to adequately predict N uptake by plants under irrigated desert conditions of Arizona. In Alabama, Burmester et al. (1989) found that a late season drought adversely affected the accuracy of GOSSYM model simulations of cotton growth and lint yield.

None of the above studies evaluated the GOSSYM model under conservation tillage systems (no-till and mulch-till) with or without poultry litter (PL) application as a N source. However, these conservation tillage systems are widely being recommended for cotton production in the southeastern US. The objective of this study was to evaluate the GOSSYM model for its ability to simulate cotton growth and lint yield under no-till and mulch-till conservation tillage systems with a winter rye cover crop and PL as a N source.

Materials and Methods

Study Location and Baseline Soil Analysis

The field study was conducted at the Alabama Agricultural Experiment Station, Belle Mina, Alabama (34º 41' N 86º 52' W) on a Decatur silt loam soil (clayey, kaolinitic thermic, Typic Paleudults) from 1996 to 1998. Before starting the experiment, soil cores were collected for the determination of baseline soil hydrologic, physical, and chemical properties (Table 1). Bulk density (Blake and Hartge, 1986), porosity and available water capacity (Klute, 1986), saturated hydraulic conductivity (constant head method), and infiltration rate (double ring infiltrometer method, Klute, 1986) were measured. Soil organic matter content (Walkley-Black, 1934) and soil N (ammonium and nitrate) using the Bio-Rad Model 550 Microplate Reader (Bio-Rad Laboratories, Hercules CA; Sims et al., 1995) were measured. Soil texture and cation exchange capacity records for the research site were also obtained.

Treatments and Experimental Design

The treatments consisted of three tillage systems (conventional till, mulch-till, and no-till), two cropping systems (cotton-winter fallow and cotton-winter rye sequential cropping), three N levels (0, 100, and 200 kg N ha^{-1}), and two N sources (ammonium nitrate and poultry litter), combined selectively to form a total of 12 treatments (Table 2). Ammonium nitrate was applied at one N rate (100 kg N ha^{-1}) only. The experimental design was a randomized complete block design with 4 replications. Plot size was 8 m wide and 9 m long and 8 rows of cotton which were 1 m apart were planted (Nyakatawa and Reddy 2000, Nyakatawa et al., 2000; Nyakatawa et al., 2001). Conventional tillage included moldboard plowing in November and disking in April. A field cultivator was used to prepare a smooth seedbed after disking. Mulch-till included tillage with a field cultivator before planting to destroy weeds and partially incorporate the rye residues. No-till included planting into un-tilled soil using a no-till planter. During the season, a row cultivator was used for controlling weeds in the conventional till system while spot applications of Roundup herbicide [isopropylamine salt of N-(phosphomethyl) glycine] were used to control weeds in the no-till and mulch-till systems.

The N contents of the PL used in the study were 27 g kg^{-1} N and 30 g kg^{-1} N in 1997 and 1998, respectively, on a dry weight basis. The N content for the PL was determined by digesting three 0.5 g samples using the Kjeldhal wet digestion method (Bremner and Mulvaney, 1982), followed by N analysis using the Kjeltec 1026 N Analyzer (Kjeltec, Sweden). The amounts of PL to supply 100 and 200 kg N ha^{-1} were calculated each year based on the mean N per cent of the PL samples. A 60% adjustment factor was used to compensate for the N availability from PL during the first year (Castellanos and Pratt, 1982). The PL was broadcasted by hand and incorporated to a depth of 5 to 8 cm by pre-plant cultivation in the conventional and mulch-till systems. The AN and PL were applied to the plots 1 day before cotton planting. A 95% adjustment factor was used to compensate for a 5% loss of N via ammonia volatilization during spreading in conventional and mulch-till systems (Alabama Cooperative Extension Service, 1989). In the no-till system, where the PL was not incorporated, a 75% adjustment factor was used to compensate for a 25% loss of N loss via ammonia volatilization during and after spreading (Alabama Cooperative Extension Service, 1989). To supply 100 kg N ha^{-1}, about 5.5 t ha^{-1} of PL were applied in conventional-till and mulch-till plots while no-till plots received about 6.0 t ha^{-1} in each year. The PL amounts were doubled to supply 200 kg N ha^{-1}. The experimental plots received a blanket application of 336 kg ha^{-1} of a 0-20-20 fertilizer to offset the effects of P and K applied through PL.

Cover Crop Establishment and Cotton Planting

The winter rye cover crop, variety Oklon, was planted on 4 Dec. 1996 and 24 Nov. 1997, and killed by Roundup herbicide about 7 days after flowering on 8 Apr. 1997 and 6 Apr. 1998. A Tye no-till grain drill (Glascock Equipment and Sales, Veedersburg, IN) was used to plant the rye cover crop at 60 kg ha^{-1} in both years. Cotton variety Deltapine NuCotn 33B was planted in all plots at 16 kg ha^{-1} using a no-till planter. A herbicide mixture of Prowl [pendimethalin, N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] at 2.3 L ha^{-1}, Cotoran [fluometuron, 1,1-dimethyl-3-(α, α, α-trifluoro-m-toyl) urea] at 3.5 L ha^{-1}, and Gramoxone extra (paraquat, 1,1'-dimethyl-4,4'-bipyridinium ion) at 1.7 L ha^{-1} was sprayed on all plots before planting on 8 May

1997 and 5 May 1998 for weed control. In addition, all plots received a band application of 5.6 kg ha^{-1} Temik [aldicarb, 2-methyl-2-(methylthio)-propionaldehyde *O*-(methylcarbamoyl)oxime] for early season control of thrips (*Thrips* spp.).

Data Collection

In order to evaluate the GOSSYM model, observed days to first square, days to first flower, and days to maturity, plant height, leaf area index (LAI), surface root biomass in the top 10 cm of the soil, total biomass, and cotton lint yield were compared to values simulated by the model. Leaf area index was measured using the AccuPAR linear ceptometer (Decagon Devices, Pullman, WA). Shoot and root biomass were measured by sampling plants with their roots intact from 0.5 m^2 quadrants from each plot. The roots were cut off from the shoots and placed in separate paper bags. The shoot and root samples were oven dried at 65°C for 72 hours before weighing. Plant height, LAI, surface root biomass, and shoot biomass were collected at 14-day intervals from 4 weeks after emergence to maturity. Cotton yield was determined by harvesting open cotton bolls in the central four rows of each plot using a mechanical stripper. Daily temperature, solar radiation, rainfall, and wind speed data needed to run the model were collected from an automated weather station at the experiment site. A summary of the weather data is presented in Fig. 2.

GOSSYM Computer Model

GOSSYM organizes information on weather, soil, and plant responses to physical conditions of the soil into subroutines. Information from the subroutines is integrated into the main program of the GOSSYM module. CLYMAT reads the daily weather information and TMPSOL calculates the soil temperatures by soil layer. SOIL is a sub-main program which calls the soil sub-programs. The soil routines provide the plant model with estimates of soil water potential in the root zone of the soil profile, an estimate of the nitrogen entrained in the transpiration stream available for growth, and an estimate of metabolic sink strength in the root system. FERTLIZ simulates the distribution of ammonium, nitrate, and urea fertilizers in the soil profiles, while GRAFLO simulates the movement of rain and irrigation water into the soil profile by gravitational flow. ET estimates the rate of evaporation from the soil surface and transpiration from the plant using the Penman equation. UPTAKE calculates the amount of nitrogen and water uptake from the root zone. CAPFLO estimates the re-wetting of dry soil from wetter soil by capillary flow. NITRIF calculates the conversion of ammonium to nitrates by bacterial processes in the soil. CHEM is a mini-main program which calls two sub-programs, PIX and PRE, to calculate the effect of chemicals on plant physiological processes. PIX simulates the effects of the plant growth regulator, mepiquat chloride, and PREP simulates the effects of a boll opener, ethephon, and defoliant chemicals.

Input weather data necessary to run GOSSYM are daily solar radiation, maximum and minimum ambient temperatures, rainfall and/or irrigation water and wind speed. Additional data necessary to run GOSSYM include emergence date, plant population, row spacing, latitude of the site, initial chemical properties of the soil (nitrogen and organic matter levels), initial physical and hydraulic properties of the soil (texture, bulk density, field capacity, water holding capacity, saturation water capacity, and permanent wilting point). The specific cultivar inputs used were those for the Deltapine cotton varieties already included in the model. The GOSSYM computer model (GOSSYM, version 4.0) was used to simulate cotton growth and lint yield from each plot each year for treatment analysis. The GOSSYM software used in this study was obtained from the USDA/ARS Cotton Physiology Research Unit at Mississippi State University, Starkville, Mississippi.

Data Analysis

Analysis of variance using the General Linear Models procedures (SAS Version 6.0) was used to analyze the data. Treatment means were separated using the least significant difference (LSD) procedure. Regression analysis procedures (Steel and Torrie, 1985;SAS Inst., 1987) were used to evaluate the relationships of simulated to measured data.

Results and Discussion

Weather Data

Daily temperature data show that the summer of 1998 was 5 to 8 °C warmer than that of 1997 (Fig. 2). It has been shown that the rates of floral initiation, square development and boll maturation in cotton increase with temperature (Chu et al., 1991; Reddy et al., 1993). Therefore, the shorter simulated duration to squaring, and measured and simulated durations to flowering and maturity stages in 1998 compared to 1997 can be attributed to higher temperatures in 1998. Cumulative water received by the crop from May to October in 1997 was 739 mm (519 mm rainfall and 220 mm irrigation) compared to 409 mm (257 mm rainfall and 150 mm irrigation) in 1998. From July to August, the crop of 1997 received a total of 342 mm of rainfall compared to 64 mm in 1998. The effects of low rainfall were not offset by irrigation water since only survival irrigation water was applied.

A water stress index of 1 indicates no water stress whereas a value of 0 indicates maximum water stress (GOSSYM-COMAX User's Manual, 1993). In both years, model simulated soil moisture stress indices (0 to 1) during cotton growth showed that the cotton crop experienced severe soil moisture stress (index < 0.5) after first flowering. During this water stress period, GOSSYM simulations of plant height, LAI, and root dry weight were poor. In 1997, the crop experienced maximum soil moisture stress between the first open boll and the 50% open boll growth stages (around mid-September) after which there was a recovery. However, in 1998, the cotton crop experienced maximum soil moisture stress from the first open boll growth stage up to maturity; consequently, the model simulated lower cotton lint yields compared to measured lint yield.

Phenological Data

Model simulations for the number of days from cotton emergence to first square, first flower, and to maturity under all tillage treatments were 1 to 4 days shorter than observed data in 1997 (Table 3). In 1998, the simulated number of days from cotton emergence to first square and to first flower were 7 to 16 days shorter than observed data, while simulated number of days from emergence to maturity under all tillage treatments was about 15 days longer than observed data (Table 3). Similar results were observed for cropping system and N treatments (data not shown). These results clearly show that the GOSSYM model performed better in simulating cotton phenology in 1997, whereas in 1998, the simulations were generally poor. The above results can be attributed to the difference in temperature and rainfall between the summers of 1997 and 1998 hence greater soil moisture stress experienced by the cotton crop in 1998. Thus, soil moisture, which significantly influenced cotton growth and yield (Nyakatawa and Reddy, 2000), played a significant role in simulations of cotton phenological data by the model. Our results are in agreement with the findings of Burmester et al., (1989) who reported poor GOSSYM model simulations of the number of days to square and to flower under drought conditions in on-farm studies in Alabama.

Growth Characteristics

Model simulations of plant height, LAI, and root dry weight under conventional till and no-till systems in 1997 were generally similar to observed data at first square and first flower growth stages 1998 (Fig. 3). However, at first open boll and maturity growth stages, simulated heights for all tillage treatments were 25% to 66% less than measured data, while simulated LAI was over 50% less than measured data (Fig. 3). Similar results were found between cropping systems (Fig. 4). Results for 1998 were generally similar to those in 1997 (data not shown). Simulated total dry weight (shoot and roots) under all tillage treatments at first open boll and maturity growth stages were similar to measured data in 1997 (data not shown). However, these figures were 45% and 30% less than measured data under no-till, at the same growth stages, respectively. In 1998, simulated total dry weight under all tillage treatments was 52 to 85% and 52 to 72% less than measured data at first open boll and maturity growth stages, respectively.

Researchers elsewhere have also reported poor GOSSYM simulations of cotton growth and yield under soil moisture stress conditions. Norton and Silvertooth (1998) found that the GOSSYM model has a limitation in its ability to predict N uptake by plants under limited moisture conditions of Arizona which lead to poor simulations in growth and yield data. On a Loring silt loam soil of Holly Springs, Mississippi, Stevens et al. (1996) found that simulations of N content of cotton by GOSSYM were generally inaccurate. Similarly, Burmester et al. (1989) reported that the GOSSYM model had problems in simulating N fertilizer availability under limited soil moisture conditions in Alabama. Studies conducted in Arizona (Norton and Silvertooth, 1998) and Mississippi (Stevens et al., 1996) also found that the GOSSYM model simulations of growth, development, and yield parameters for cotton were significantly lower than measured data. At Lubbock Texas, Staggenborg et al. (1996) found that the GOSSYM model was able to accurately predict LAI early in the season, but over-estimated LAI by 21% late in the season. From their study in Arizona, Norton and Silvertooth (1998) reported that despite greater values of GOSSYM simulated NO_3–N levels compared to measured data, the model still simulated N stress suggesting limitations in its ability to predict N uptake by cotton under irrigated desert conditions. The rapid decline in measured LAI data after the boll opening stage observed in our study is in agreement with the findings of Hopkins et al. (1988).

Lint Yield

In 1997, simulated lint yield under conventional till was not significantly different from measured lint yield, whereas under mulch-till and no-till, simulated lint yields were 220 kg ha^{-1} greater than and 220 kg ha^{-1} less than measured lint yields, respectively, (Fig. 5). In 1998, simulated lint yields under conventional till, mulch-till, and no-till were 270 kg ha^{-1}, 130 kg ha^{-1} and 210 kg ha^{-1}, respectively, less than measured lint yields. Simulated lint yields under cotton-winter fallow cropping were 160 kg ha^{-1} and 190 kg ha^{-1} less than measured yields in 1997 and 1998, respectively. In 1997, simulated and measured lint yields under cotton-rye cropping system were similar, whereas in 1998, simulated lint yield under cotton-rye cropping was 220 kg ha^{-1} less than measured yield (Fig. 5).

Research at Lubbock, Texas demonstrated that wheat cover crop residues provided a favorable micro-environment such as higher soil moisture for the growth and development of cotton, which resulted in significant lint yield increases (Lascano et al., 1994). The low simulated lint yields, especially in the no-till system, in variation to measured lint yields, clearly show that the GOSSYM model simulations did not account for the benefits of conservation tillage, such as increased infestation of root mycorrhizae which stimulate the root uptake of water and nutrients (Ellis et al., 1992), increased soil organic matter, increased water infiltration, and soil moisture conservation (Stein et al., 1986; Seta et al., 1993; Vyn et al., 1999; Nyakatawa and Reddy, 2000, Nyakatawa et al., 2001).

Regression analyses of simulated versus measured cotton lint yield data showed that the GOSSYM model simulations of cotton lint yield under all tillage systems in 1997 and 1998 were generally poor (data not shown). However, there were higher and significant linear relationships between simulated and measured cotton lint yield data in 1997 compared to 1998, suggesting better GOSYYM model simulations for cotton lint yield in 1997 compared to 1998. Similar results were found for regression analyses of simulated versus measured cotton lint yield data under the cropping systems (data not shown). The poorer simulations for cotton yield in 1998 compared to 1997 can largely be attributed to severe soil moisture stress simulated by the model due to severe drought conditions of 1998. Burmester et al. (1989) reported that an early season drought resulted in GOSSYM model simulating cotton lint yields which were 60% to 80% lower than measured yield in Alabama. Staggenborg et al. (1996) found that the GOSSYM model underestimated potential evapotranspiration under semi-arid conditions in Texas, which may affect simulations of cotton growth and yield.

Simulated lint yield for at the 0 kg N ha^{-1} level was 390 and 240 kg ha^{-1} less than measured lint yield, respectively, in 1997 and 1998 (Fig. 5). Simulated lint yields for the 100 kg N ha^{-1} AN and 100 kg N ha^{-1} PL treatments were similar to measured yields in 1997. In 1998, simulated lint yield at the 100kg N ha^{-1} AN level was 280 kg ha^{-1} less than measured yield, while simulated and measured yields for the 100 kg N ha^{-1} PL treatment were similar. Simulated yield for the 200 kg N ha^{-1} PL treatment was about 300 kg ha^{-1} less than measured yield in both years (Fig. 5). Compared to conventional till, no-till with winter rye cover cropping had 24% to 56% and 33% to 80% higher volumetric soil moisture in 1997 and 1998, respectively (Nyakatawa and Reddy, 2000), which explains the higher measured growth, yield, and yield parameters under no-till in both years. Soil moisture conservation in no-till and cover cropping systems have also been reported by other researchers (Gallaher, 1977; Harman et al., 1989; Bordovsky et al., 1994).

The greater measured growth and yield data under the 200 kg N ha^{-1} PL treatment were largely attributed to increased soil moisture conservation due to the high water holding capacity of PL. The PL treatments had 10 to 53% significantly greater volumetric soil water content compared to AN treatments (Nyakatawa and Reddy, 2000). The low values of simulated data compared to measured data at 100 and 200 kg N ha^{-1} PL levels (Fig. 5) show that the GOSYYM model did not account for the effects of PL on soil moisture conservation which were depicted in measured data. Model simulations showed severe soil moisture stress for all treatments, irrespective of the N source, especially in 1998, the low rainfall year.

In Mississippi, Stevens et al. (1996) reported that the GOSSYM model simulations of water stress during boll set period reduced cotton yield potential to a level where residual N and soil N mineralization satisfied the crop's N requirements. As a result, the model incorrectly simulated cotton yield response to the 90 kg N ha^{-1} recommendation for the area. Norton and Silvertooth (1998) found that the GOSSYM model simulated similar values of soil nitrate for different cotton species and different N management strategies under limited soil moisture conditions in Arizona. These studies also support the need for model modifications to enable it to accommodate different cropping scenarios. Our study shows that the GOSSYM model does not take into account the effect of crop residues and poultry litter on soil moisture, and therefore could not account for the greater soil moisture retention and the improvement in other soil properties of no-till and cover cropping management systems. Lower values of simulated cotton growth parameters and lint yield compared to measured data can be attributed to this limitation of the model. Therefore, the subroutines dealing with soil moisture availability, specifically, RUNOFF and GRAFLO need to be modified to enable GOSSYM to be able to simulate the benefits of no-till, cover cropping, and PL effects on soil water conservation.

Conclusions

Results from our study show that the GOSSYM model generally performed better in simulating cotton growth parameters (plant height, LAI, and root dry weight) from first square up to first flower growth stages. Thereafter, simulated data were significantly lower than measured data, which was attributed to soil moisture stress after the first flower growth stage. This study shows that the GOSSYM model was not able to simulate conservation tillage and PL application benefits such as soil moisture retention which significantly improve cotton crop growth and yield. The GOSSYM model needs modifications in sub-routines dealing with soil moisture availability so that it can simulate cotton growth and lint yield under conservation tillage systems with winter rye cover cropping and PL as the N source to improve its usefulness in the southeastern U.S.

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Table 1. Physical, chemical, and hydrological properties of the Decatur silt loam soil, Belle Mina, AL, Nov. 1996.

Depth (cm)	Sand	Silt	Clay	SWC	FC	PWP	AWC	f	ρ_b (g cm^{-3})	I	K_{sat}
	-------------------------------			%			-------------------------------			(mm hr^{-1})	
Physical and Hydrological Properties											
0-30	15	58	26	33	20	11	9	49	1.35	28	15
30-60	10	46	44	32	26	16	10	46	1.42	-	-
60-90	9	34	57	32	29	19	10	47	1.41	-	-

Depth (cm)	pH	OM (%)	NH_4	NO_3	P	Ca	Mg	K	CEC
			-----------------------------			mg kg^{-1}		-----------------------------	--cmol kg^{-1}--
Chemical Properties									
0-30	6.2	1.42	95.4	28.0	40.5	1299.2	53.4	76.2	13.3
30-60	5.7	0.43	54.6	37.2	7.5	1248.0	51.4	24.6	10.2
60-90	5.2	0.22	58.8	41.6	3.0	851.2	83.9	21.9	8.8

SWC = saturation water content; FC = field capacity; PWP = permanent wilting point; AWC = available water content; f = porosity; ρ_b = bulk density; I = infiltration rate; Ksat = saturated hydraulic conductivity; CEC = cation exchange capacity.

Table 2. Treatments used in the cotton study at Belle Mina, AL, 1996 to 1998.

Trt #	Description of treatments
1	Cotton-winter rye cropping, conventional-till, no nitrogen applied
2	Cotton-winter fallow cropping, conventional-till, 100 kg N ha^{-1} (Ammonium nitrate)
3	Cotton-winter fallow cropping, no-till, 100 kg N ha^{-1} (Ammonium nitrate)
4	Cotton-winter rye cropping, conventional-till, 100 kg N ha^{-1} (Ammonium nitrate)
5	Cotton-winter rye cropping, Conventional-till, 100 kg N ha^{-1} (Poultry litter)
6	Cotton-winter rye cropping, Mulch-till, 100 kg N ha^{-1} (Ammonium nitrate)
7	Cotton-winter rye cropping, Mulch-till, 100 kg N ha^{-1} (Poultry litter)
8	Cotton-winter rye cropping, No-till, 100 kg N ha^{-1} (Ammonium nitrate)
9	Cotton-winter rye cropping, No-till, 100 kg N ha^{-1} (Poultry litter)
10	Cotton-winter fallow, No-till, No nitrogen applied
11	Cotton-winter rye cropping, No-till, 200 kg N ha^{-1} (Poultry litter)
12	Weed free fallow (no crop planted)

Table 3. Observed and GOSSYM model simulated of phenological data of cotton under no-till (NT), mulch-till (MT), and conventional till (CT) systems, Belle Mina, AL, 1997 and 198 (Standard error of means in parenthesis).

	Days to first square		Days to first flower		Days to maturity	
	1997	1998	1997	1998	1997	1998
Tillage Systems						
CT						
Observed	41 (1.8)	44 (1.5)	68 (2.2)	57 (1.4)	162 (0.0)	107 (0.0)
Simulated	37 (0.0)	28 (0.0)	62 (0.0)	51 (0.0)	158 (1.3)	122 (2.9)
MT						
Observed	38 (1.6)	43 (1.8)	63 (2.3)	55 (2.3)	162 (0.0)	107 (0.0)
Simulated	37 (0.0)	28 (0.0)	62 (0.0)	51 (0.0)	161 (7.4)	124 (0.0)
NT						
Observed	38 (2.4)	42 (2.0)	63 (2.2)	55 (2.1)	162 (0.0)	107 (0.0)
Simulated	37 (0.0)	28 (0.0)	62 (0.0)	51 (0.0)	158 (1.2)	122 (5.4)

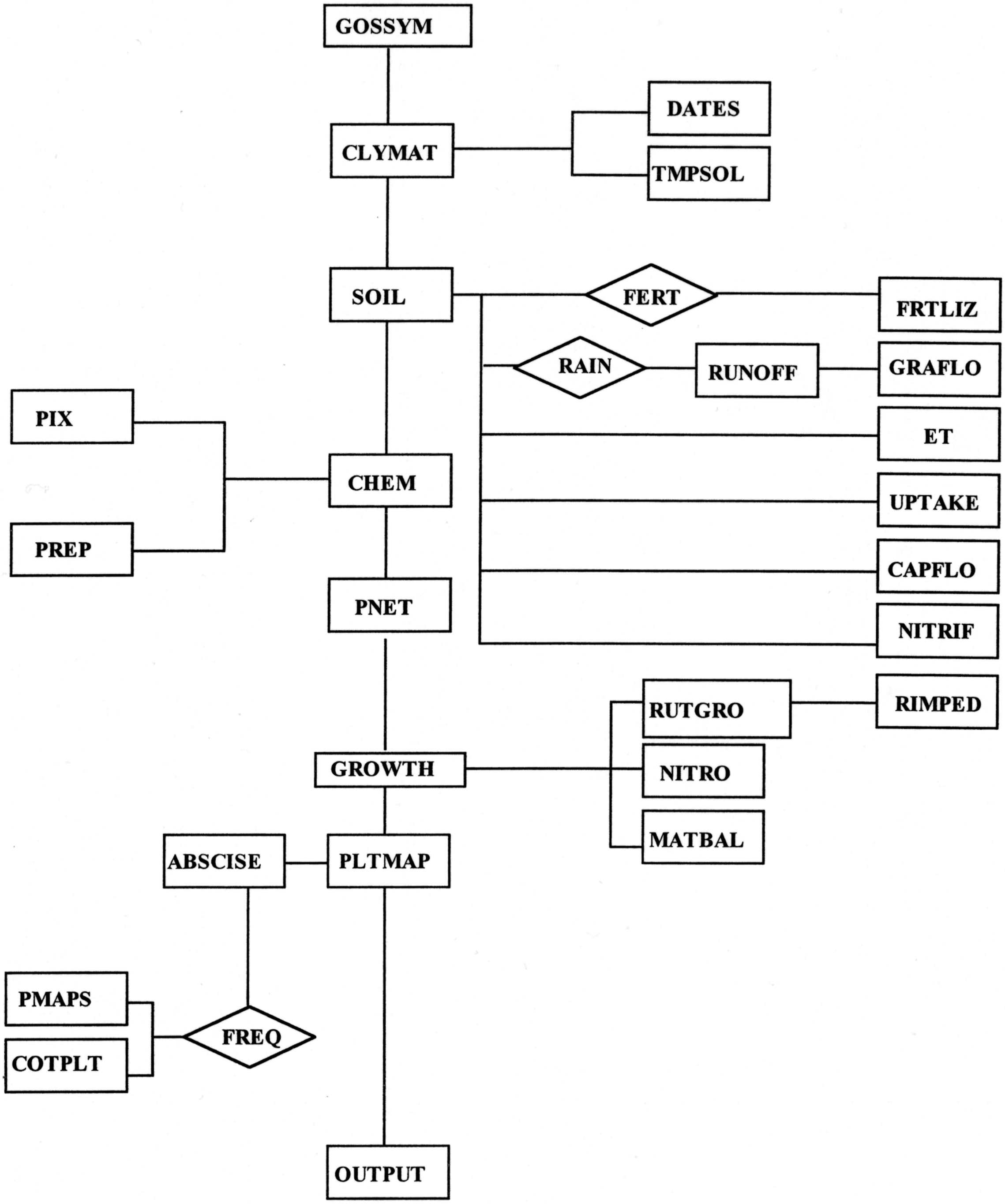

Figure 1. Model structure and program flow of the GOSSYM model.

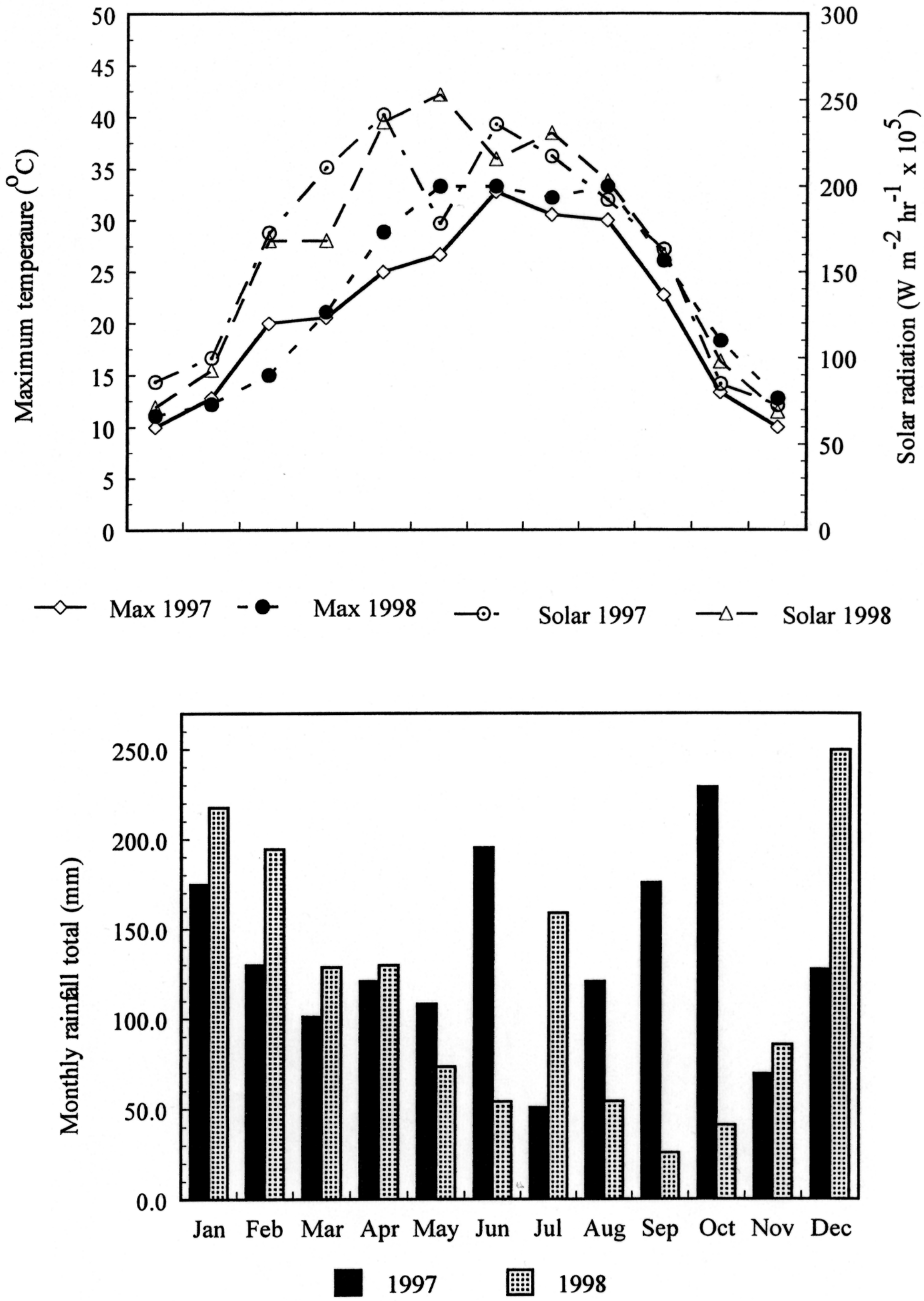

Figure 2. Summary of weather data at Belle Mina, AL, 1997 and 1998.

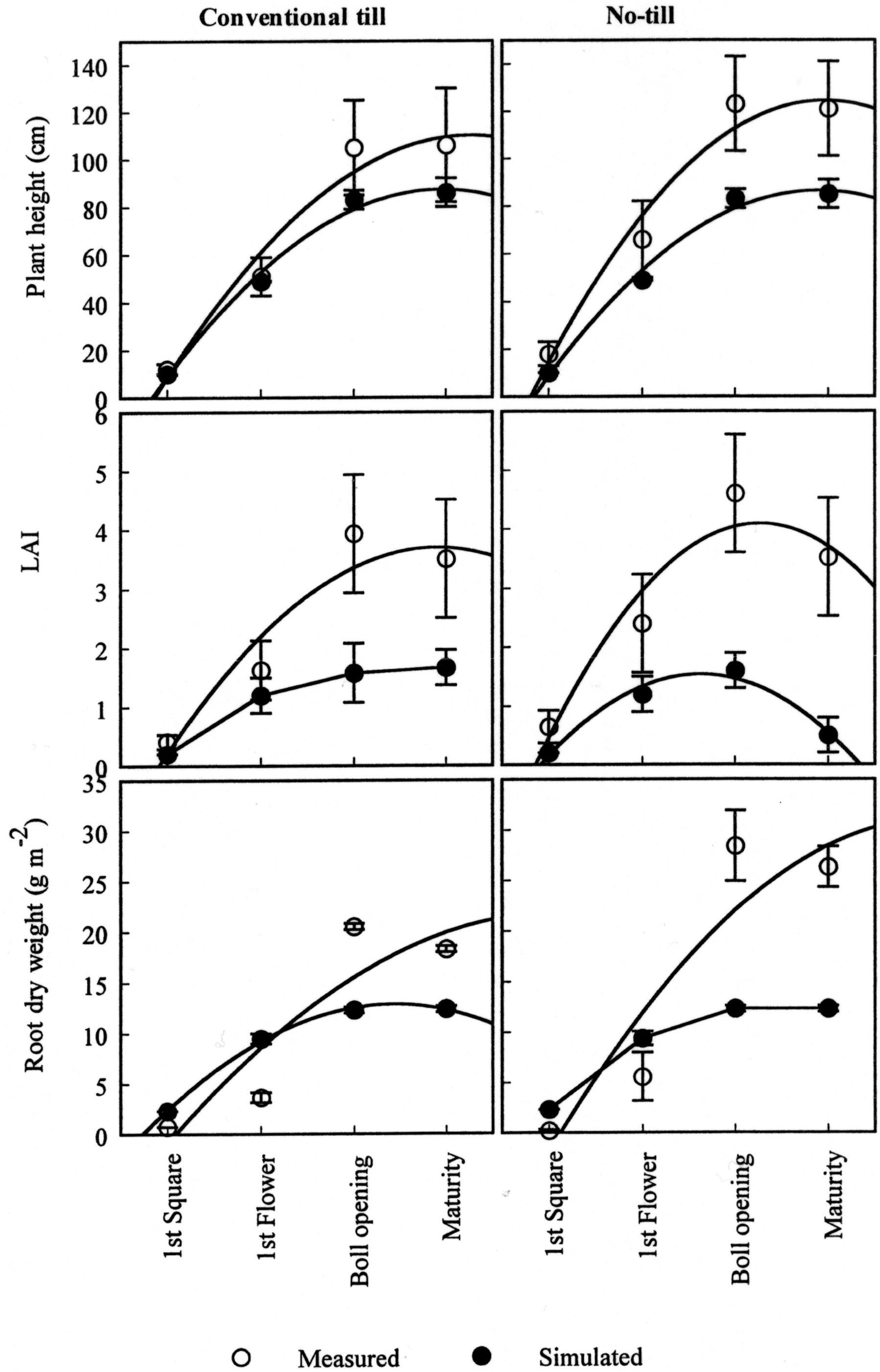

Figure 3. Growth curves for measured and GOSSYM simulations of cotton growth parameters under conventional and no-till systems at different growth stages, Belle Mina, AL 1997 (Error bars - S.E. of means).

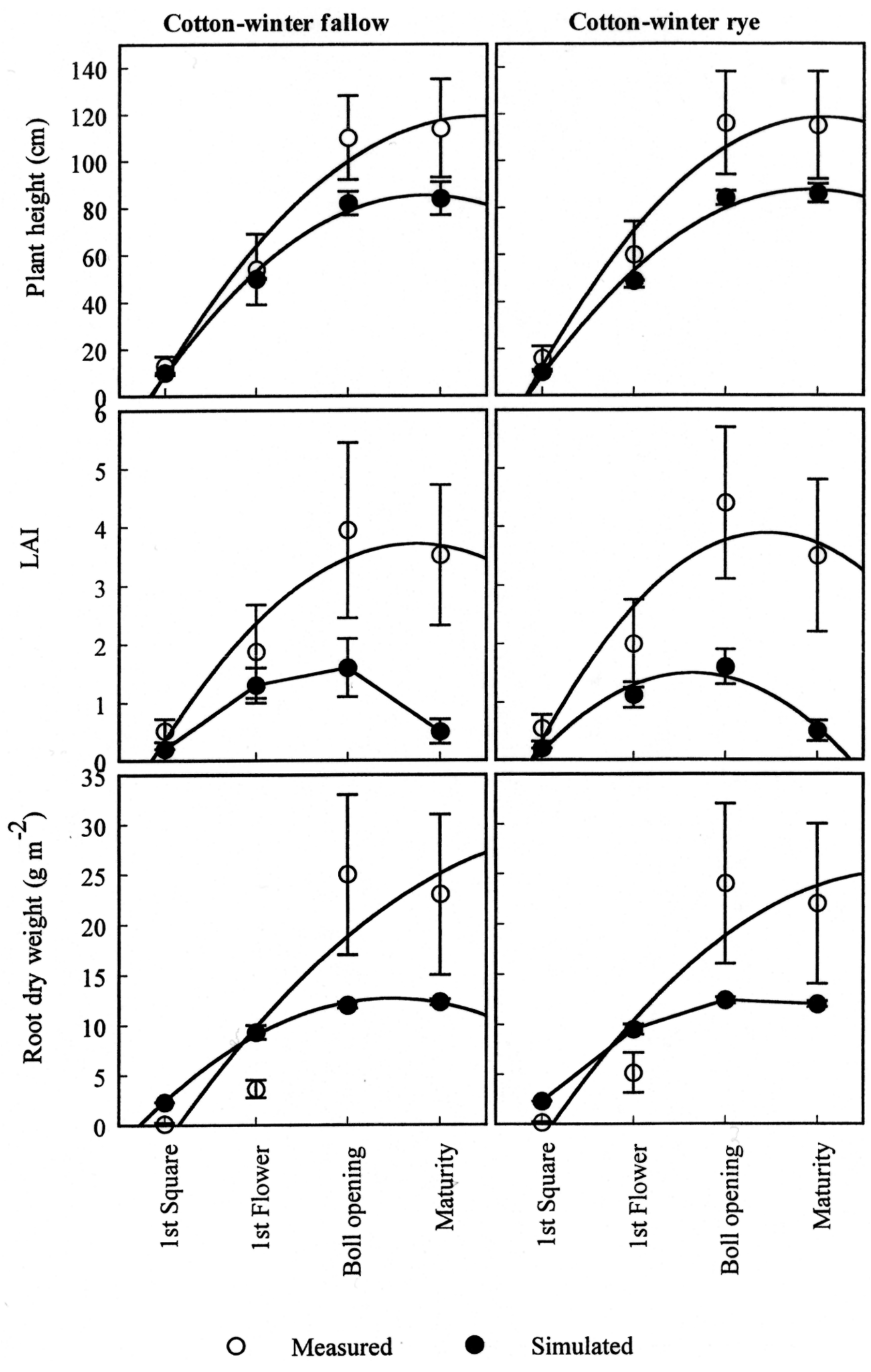

Figure 4. Growth curves for measured and GOSSYM simulations of cotton growth paramets under cotton-winter fallow and cotton-winter fallow corpping systems at different growth stages, Belle Mina, AL, 1997 (Error bars = S.E. of means).

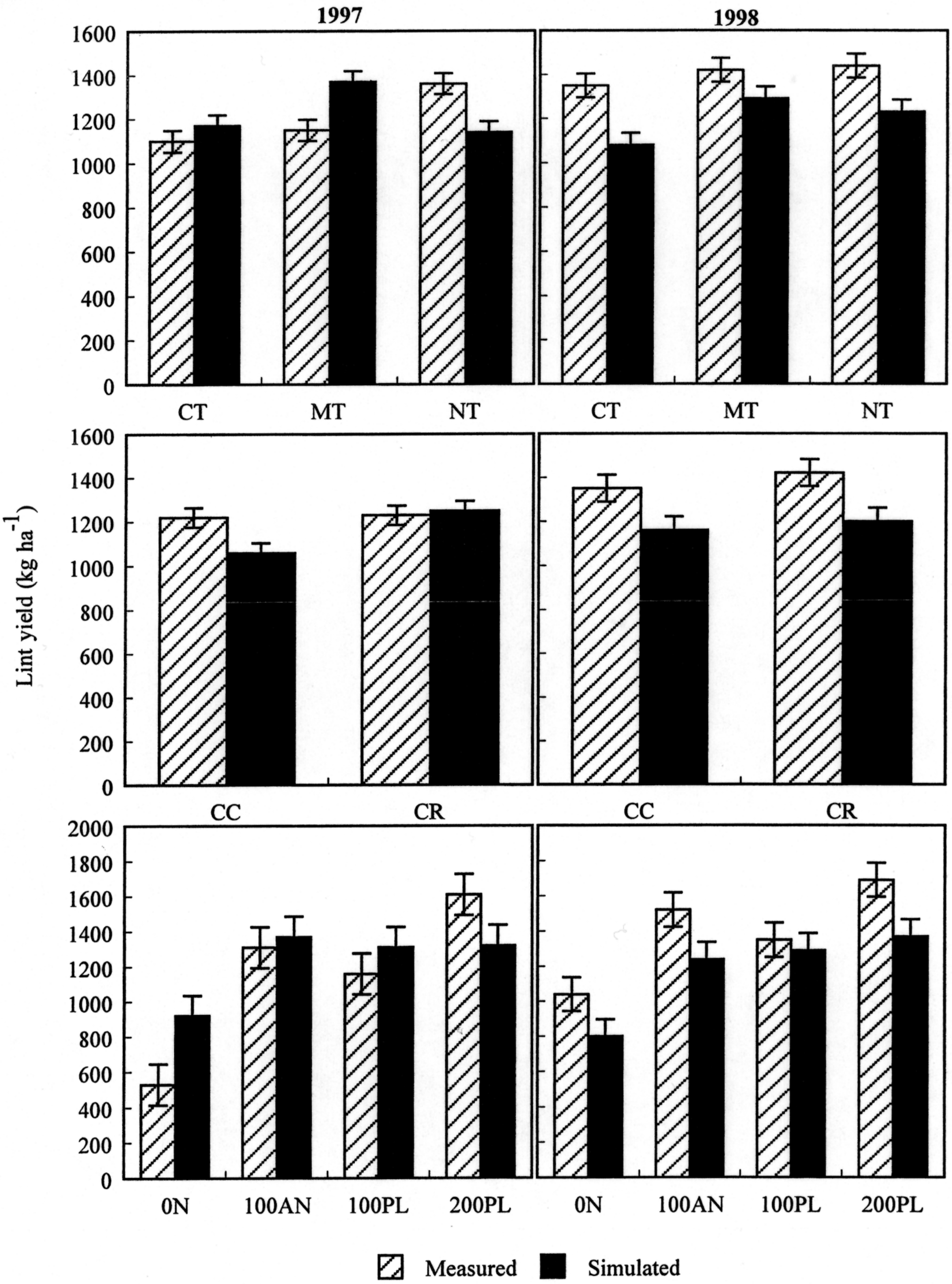

Figure 5. Measured and GOSSYM simulated cotton lint yeilds under conventional till (CT) and no-till (NT) systems; cotton-winter fallow (CF) and cotton-winter rye (CR) cropping systems; and N from ammonium nitrate (AN) and poultry litter (PL), Belle Mina, AL, 1997 and 1998 (Error bars = S.E. of means).