Using New Data Sets to Revise CSM-CROPGRO-Cotton

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Research Report 252
Crop and Soil Sciences Department
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Raleigh, NC 27695-7620
January, 2019

ACKNOWLEDGEMENTS

We would like to thank Cotton Incorporated for partially funding this research. We also express appreciation to the College of Agricultural and Life Sciences at North Carolina State University, and to USDA-NIFA for financial support of this project through Hatch Project No. NC02468.

The purpose of this project was to collate available cotton data sets from researchers in Arizona, Texas, Georgia, and North Carolina, and prepare DSSAT data files for all studies. This included summarizing field data for all of the studies, and creating DSSAT FileAs (harvest summary data), and FileTs (time series data). Researchers in Arizona, Texas, and North Carolina all found it necessary to change not only soil profile parameters and cultivar genetic coefficients, but also program code and/or parameter values in the species file (COGRO046.SPE) in order to accurately simulate cotton response to environmental and management conditions for particular experiments. If the model is working correctly, only one version of the source code and one version of the species file should be required, as well as one soil profile per field, and one set of genetic coefficients per cultivar. Therefore, an additional objective was to create one version of species, soil, cultivar, and ecotype coefficients/parameters to run with a common version of the DSSAT executable file. Since the standard CSM-CROPGRO-Cotton Version 4.6 code underestimated reference evapotranspiration (ET) under the arid conditions present at some locations in AZ and TX, we used a version of the executable file provided by Kelly Thorp. In December, 2018 we obtained Version 4.7 with Kelly Thorp's ET routines. We have compared results between Version 4.6 and 4.7, and results reported here are for Version 4.7.

Description of Data Sets

Arizona FACE experiments:

Three years of data were available from experiments performed using free-air CO_2 enrichment (FACE) technology in a field at the University of Arizona Maricopa Agricultural Center (Mauney et al., 1992; Kimball et al., 1992; Hunsaker et al., 1994; Mauney et al., 1994; Thorp et al., 2014). Data for the 1989 experiment were included with the DSSAT 4.6 release. Data files for the 1990 and 1991 experiment were provided by K. R. Thorp. The soil was a Trix clay loam, and the cultivar was 'Deltapine 77' in all three years. Planting dates were 18 April 1989, 23 April 1990, and 16 April 1991. There were 9.8 plants m^{-2}, planted on raised beds with 1.02 m (40") row spacing. In 1989, there were two treatments: 1) control with 350 µmol $µmol^{-1}$ CO_2, and 2) enriched for 14 h per day to 550 µmol $µmol^{-1}$ CO_2. Both treatments were well-irrigated. In 1990 and 1991, 'wet' and 'dry' ambient and enhanced CO_2 treatments were created in a split plot design. The dry treatments received 75% as much irrigation water as the wet treatments in 1990, and 67% in 1991. The ambient CO2 treatments in 1990 and 1991 averaged 370 µmol $µmol^{-1}$. (This was measured in 1990 and 1991, but apparently not in 1989—the 350 µmol $µmol^{-1}$ value for 1989 was set in the original DSSAT files and in the publication by Kimball et al., 1992). Data collected throughout the season included canopy height; leaf area index (LAI); leaf, boll, root, stem, and canopy dry weights; and number of bolls m^{-2}. Lint and seed yield and total biomass were determined at final harvest.

Arizona AgIIS experiment:

This experiment, conducted in 1999 at the University of Arizona Maricopa Agricultural Center to evaluate the Agricultural Irrigation Imaging System (AgIIS) for monitoring crop water and N stress, compared cotton responses to two irrigation levels and two N fertilizer levels (El-Shikha et al., 2008; Thorp et al., 2014). Data files were provided by K. R. Thorp. Cotton cultivar 'Deltapine 90b' was planted on 16 April 1999 on a Casa Grande silty loam soil at a plant population of 9.4 plants m^{-2}, and a row spacing of 1.02 m. Treatments included 1) optimal water and optimal N, 2) optimal water and low N, 3) low water and optimal N, and 4) low water and low N. Data measured weekly included number of bolls m^{-2}; canopy height and width; number of mainstem nodes; leaf, stem, boll, and canopy weight; and LAI. Final yield was determined by mechanical harvest of undisturbed crop rows.

Arizona FISE experiment:

The FAO-56 Irrigation Scheduling Experiments (FISE) were conducted in 2002 and 2003 at the University of Arizona Maricopa Agricultural Center on a Casa Grande sandy loam soil (Hunsaker et al., 2005; Thorp et al., 2014). Data files were provided by K. R. Thorp. For model comparisons, only data from the standard FAO-56 irrigation scheduling treatments were used, since irrigation could vary by plot for the other treatments. There were six sub-treatments consisting of three plant densities (sparse, typical, and dense) and two levels of N fertilization. Cotton cultivar 'Deltapine 458/RR, Bollgard/Roundup Ready' was planted on 15-16 April 2002 and 7-8 April 2003 into a dry seedbed. Row spacing was 1.02 m. Twin rows were used to obtain the dense plant population, and the crop model is not set up to handle twin rows. Measured data included canopy height and width throughout the season in both years, and canopy weight in 2003. Final yield was also determined. Neutron probe measurements of soil moisture were made at 0.2 m increments to a depth of 2.8 m to estimate cotton ET.

Texas root growth and soil water extraction study:

This study was performed in Temple, TX, and examined root growth and water extraction by growing cotton in a weighing lysimeter (Bland and Dugas, 1989). Data files were included in the DSSAT 4.6 release. The soil was a Frio silty clay loam. Cotton cultivar 'GP3774' was planted using a 0.61-m row spacing at a population of 15 plants m^{-2}. Emergence was on 4 June 1984. Soil water content was measured at 10 depths with a neutron probe. Root length density was estimated weekly using a color video camera to count roots that were visible against clear observation tubes installed horizontally at 0.2 m intervals. LAI was estimated from leaf length measurements.

Texas irrigation timing experiment:

This irrigation experiment was conducted at the Texas A&M AgriLife Research Center at Halfway, Texas from 2010 to 2013 (Bordovsky et al., 2015; Adhikari et al., 2016). Data files were supplied by A. S. Ale. Soil at the site transitioned from a Pullman clay loam to an Olton loam. There were 27 irrigation treatments, consisting of three levels of irrigation (low, medium, high) applied during three irrigation periods (early vegetative, reproductive, and maturation). Cotton cultivar 'Fibermax 9680 B2RF' was planted at a 3.8-cm depth on 11 May 2010 (5.8 seeds m^{-2}), 11 May 2011 (5.2 seeds m^{-2}), 9 May 2012 (5.6 seeds m^{-2}), and 13 May 2013 (6.2 seeds m^{-2}) at 1.0-m row spacing. Measurements included seed cotton and lint yield.

Texas deficit irrigation experiment:

This irrigation experiment was conducted at the Chillicothe Research Station in 2012 on an Abilene clay loam soil (Modala, 2014; Modala et al., 2015). Data files were supplied by A. S. Ale. Cotton cultivar 'Deltapine 0912' was planted in 1.02 m rows at a plant population of 9.7 plants m^{-2} on 23 May. There were four irrigation scheduling treatments: 1) 100% ET replacement, 2) 75% ET replacement, 3) tensiometer-based irrigation scheduling, and 4) soil moisture-based irrigation scheduling. Data measured during the season included LAI, canopy height, and mainstem node numbers (not available). Final seed cotton and lint yields were also measured.

Texas cover crop impact study:

This study was conducted at the Chillicothe Research Station from 2011-2015, but cotton data were available only from 2013-2015 (Adhikari et al., 2017). Data files were supplied by A. S. Ale. There were four treatments: 1) irrigated cotton without a cover crop, 2) irrigated cotton with winter wheat as a cover crop, 3) dryland cotton without a cover crop, and 4) dryland cotton with winter wheat as a cover crop. Cotton cultivar 'Deltapine 1219' was planted on 3 June 2013, 20 May 2014, and 23 June 2015 in 1.0 m rows at a rate of 13 seeds m^{-2}. In addition to final seed cotton yield, soil water measurements at 0-

15, 15-30, 30-45, 45-60, 60-75, 75-90, 90-105, and 105-120 cm depth intervals were available at two-week intervals.

Georgia irrigation study:

This irrigation study, conducted at the Stripling Irrigation Research Park in Camilla, GA, was included in the DSSAT 4.6 release (Guerra et al., 2005). We found that canopy weight did not equal the sum of leaf, stem, and boll in FileT, so we changed canopy weight to equal the sum of leaf, stem, and boll. We were unable to find the original research report on line. The coordinates given for location of the weather station do not match those for the current weather station at this site. Therefore, we used a different location code for this experiment and later experiments conducted at the research park. According to the files included with DSSAT 4.6, cultivar 'Deltapine 555 BG/RR' was planted on 6 May 2004 at a plant population of 11 plants m^{-2} using 0.90 m row spacing. Soil was Lucy loamy sand. There was a well-irrigated and rainfed treatment. Data collected throughout the season included canopy height; LAI; and leaf, stem, boll, seed cotton, and canopy dry weight.

Georgia primed acclimation study:

This irrigation study was conducted in Camilla, GA, and examined the potential for reduced prebloom irrigation, called primed acclimation (PA), to increase water use efficiency (Meeks, 2017; Meeks et al., 2017; Webster and Christ, 2016). Data files were supplied by Emily Christ. Time series data were supplied by Calvin Meeks. Cotton cultivar 'FiberMax© 1944 GLB2' (Bayer Crop Science) was planted at a 2.5-cm depth on 13 May 2014 and 11 May 2015. Cultivar 'Phytogen 339' was also planted in 2015. Row spacing was 0.91 m, and seeding rate was 13 seeds m^{-1} row. Final plant stand averaged 13.7 plants m^{-2}. Treatments included: 1) well-watered with soil-water potential (SWP) level of −20 kPa used as the prebloom irrigation threshold; 2) plants irrigated at a soil moisture threshold of −40 kPa prior to flowering; 3) plants irrigated at a soil moisture threshold of −70 kPa prior to flowering; 4) plants irrigated at a soil moisture threshold of −100 kPa prior to flowering; and 5) rainfed. Treatments 1 through 4 were irrigated at a threshold of −35 kPa after first bloom. All treatments (including Treatment 5) were irrigated within three days of planting with 2.54 cm of water to ensure a uniform stand and activate herbicides. Data collected included number of mainstem nodes, and plant height (ground to apical meristem) throughout the season. Final seed cotton yield was determined using a scale immediately adjacent to the field. Seed cotton dry weight was estimated by assuming a 6% moisture rate.

Georgia high-biomass rye cover crop study:

This irrigation experiment, conducted near Tifton, GA, compared a high-biomass rye cover crop system to conventional tillage (Meeks, 2017; Meeks et al., 2018; Webster and Christ, 2016). Only the conventional tillage treatments are included in the files created for DSSAT. Data files were supplied by Emily Christ. Time series data were supplied by Calvin Meeks. Soil was a Tifton loamy sand. Cotton cultivar 'FiberMax© 1944 GLB2' (Bayer Crop Science) was planted on 7 May 2014 and 11 May 2015 at a depth of 2.5 cm with 0.91 m row spacing. Seeding rate was 12.1 plants m^{-2}. There were three irrigation treatments: 1) irrigation triggered at -0.4 MPa; 2) irrigation triggered at -0.5 MPa; and 3) irrigation triggered at -0.7 MPa. Data collected included plant height (ground to apical meristem), number of mainstem nodes, and final lint yield. Seed cotton weight was determined using a scale immediately adjacent to the field. Seed cotton dry weight was estimated by assuming a 6% moisture rate.

Georgia predawn leaf water potential irrigation study:

This irrigation experiment, conducted at the Stripling Irrigation Research Park in Camilla, GA, evaluated the use of predawn leaf water potential as an irrigation trigger (Chastain et al., 2016; Webster and Christ, 2016). Data files were supplied by Emily Christ. Time series data were supplied by Daryl Chastain. Cultivars 'Phytogen 499 WRF' (Dow AgroSciences) and FiberMax© 1944 GLB2 (Bayer Crop Science) were planted on 2 June 2014 at a 0.91-m row spacing and a seeding rate of 12.6 plants m^{-2}. Supplemental irrigation was supplied to all treatments prior to squaring using overhead sprinkler irrigation. After treatments were established, irrigation was supplied through drip tapes. Treatments included: 1) Georgia Cooperative Extension checkbook recommendations (Collins et al., 2014); 2) predawn leaf water potential threshold of −0.5 MPa; 3) predawn leaf water potential threshold of −0.7 MPa, 4) predawn leaf water potential threshold of −0.9 MPa; and 5) rainfed. Data collected included number of mainstem nodes, and plant height (ground to apical meristem) throughout the season. Seed cotton and lint yields were available at harvest.

North Carolina planting date and irrigation study:

This study, conducted in 2015 and 2016 at the Peanut Belt Research Station located near Lewiston-Woodville, examined the impact of cultivar, planting date, and irrigation on crop growth and yield (Spivey, 2017; Spivey et al., 2018). The soil was a Norfolk sandy loam. Row spacing was 0.91 m, and seeding rate was 12 plants m^{-2}. Treatments were a factorial of two cultivars and three planting dates, grown under fully-irrigated and rainfed conditions. Cultivars used in the study were the early-maturing cultivar Phytogen (PHY) 333WRF and the mid-maturing cultivar PHY499WRF (Dow AgroScience, Indianapolis, IN). Planting dates were 6 May, 21 May, and 8 June 2015; and 10 May, 24 May, and 8 June 2016. Irrigation was supplied through sub-surface drip tape. Data included weekly measurements of canopy height and mainstem node numbers; observed dates of pinhead square, first flower, first open boll, and physiological maturity; and leaf, stem, boll, and canopy dry weights and leaf area taken at these four developmental stages. An additional destructive harvest was made three weeks after first bloom in 2016.

Approach

The original parameterization of this model was apparently based on only three data sets (AZ FACE 1989, GA 1984 irrigation study, and the Temple, TX root growth and soil water extraction study). We found inconsistencies in canopy dry weight values for both the AZ FACE 1989 and GA 1984 irrigation data sets. The other data set contained no dry weight data. With the addition of more data sets, and the correction of canopy dry weight values (assuming the values for leaf, stem, and boll were correct), it became clear that some changes to species coefficients would improve model performance. The most complete data sets were those from the Arizona FACE experiments, since these included root weight as well as leaf, stem, boll, seed cotton, and canopy weights throughout the season. We used data from the ambient CO_2 treatment for the 1989 study to adjust species file coefficients related to partitioning, senescence, and root growth. Data from the North Carolina study were used, together with the FACE experimental data from 1989 and 1991, to modify species temperature functions. Coefficients contained in the COGRO046.SPE file were adjusted and simulated mainstem node numbers; canopy height; and leaf, stem, boll, root, and canopy dry weights were visually compared to observed values in an iterative process. Coefficients in cultivar, ecotype, and soil files were also adjusted. For instance, available soil water in the original soil profile for Trix clay loam was considerably lower than specified for this soil by USDA-NRCS (2017), and seemed to be too low to support the amount of growth observed in the AZ FACE experiments.

Results

We modified the species file considerably. These changes have primarily involved partitioning, root growth, senescence, and temperature functions. Partitioning among leaf, stem, and root is a function of V-stage. Figure 1 shows the changes which were required in the proportion of increase in dry weight that goes to leaf and stem as a function of V-stage.

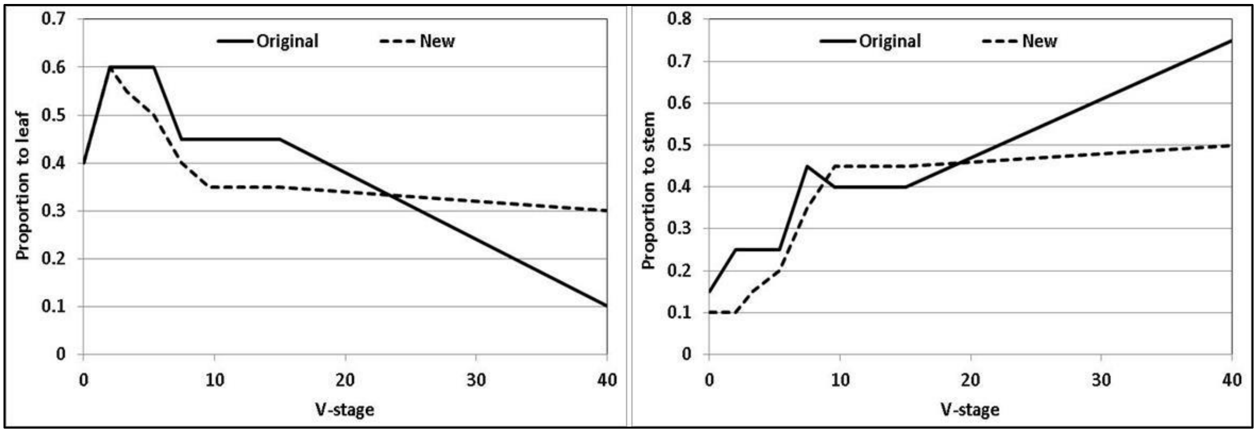


Figure 1. Comparison of leaf and stem partitioning factors used in original CSM-CROPGRO-Cotton Version 4.6, and new ones fit using data from AZ, TX, GA, and NC.

Another change involved the increase in root depth through time (Fig. 2). In NC soils in particular, we found that we needed to slow down increase in rooting depth early in the season. In reality, root growth should be affected by soil chemical and physical factors, in addition to soil temperature.

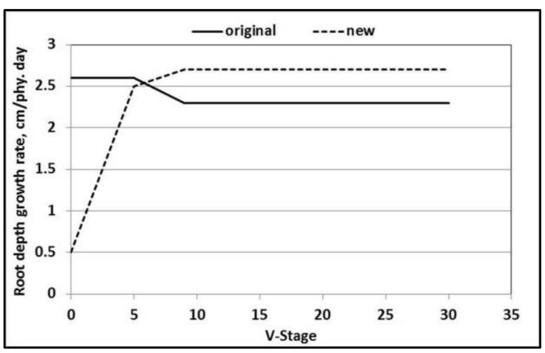
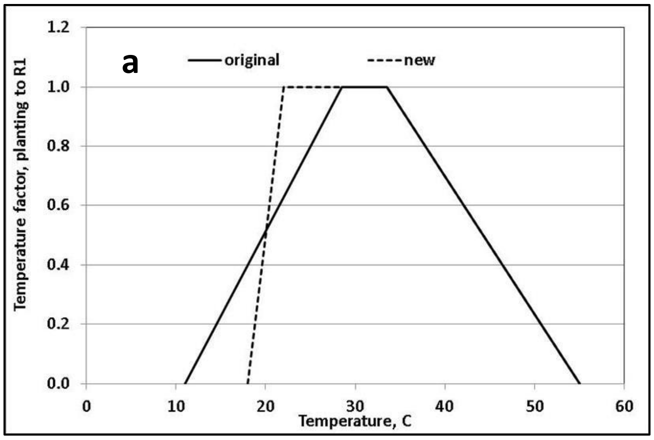


Figure 2. Comparison of original and new root depth growth rate per physiological day, as a function of V-stage.

Three temperature functions have also been modified: 1) factor that sets temperature effect on rate of vegetative development from planting to R1 (Fig. 3a); 2) factor that sets temperature effect on rate of increase in canopy height and width (Fig. 3b); and 3) TEMPOD, the factor that modifies maximum rate of flower and boll addition under non-optimal temperatures (Fig. 4). There were enough temperatures above 40 °C during the boll set period in Arizona in 1991 to delay simulated boll set below the observed rate if the initial 40 °C cutoff was used. It appears that cotton requires higher temperatures for vegetative growth than originally specified, as shown in Figure 3.



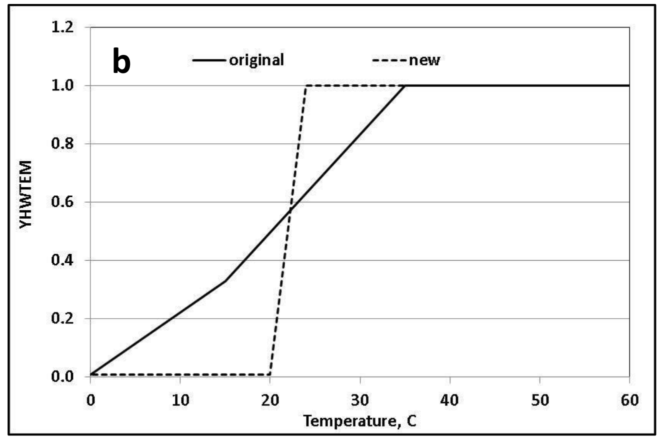


Figure 3. Comparison of original and new factor that a) sets temperature effect on rate of vegetative development from planting to R1; and b) sets temperature effect on rate of increase in canopy height and width.

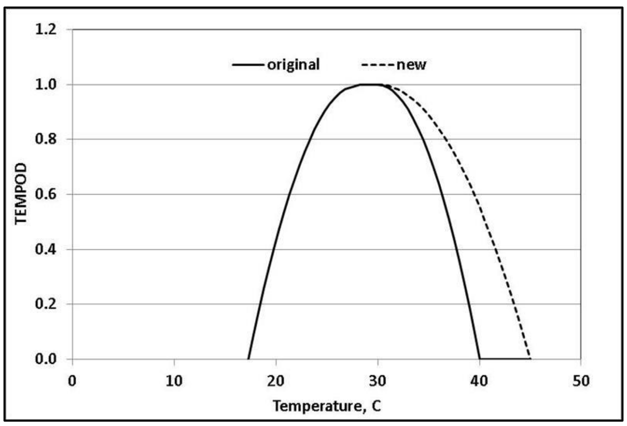


Figure 4. Comparison of original and new values for TEMPOD, factor that modifies maximum rate of flower and boll addition under non-optimal temperatures.

Other changes to parameters included in the species file are summarized in Table 1.

Table 1. Changes to other CSM-CROPGRO-Cotton species parameter values.

Parameter	Definition	Original value	New value
EVMODC	modifier of rate of vegetative node appearance for the first few nodes	5	0
PORPT	ratio of petiole mass to leaf mass	0.0	0.1
RTDEPI	depth of roots at emergence	25 cm	15 cm
RFAC1	root length per unit weight	12,000 cm/g	10,000 cm/g
RTSEN	fraction of roots which are senesced per physiological day	0.008	0.000
SENRT2	proportion of leaf weight senesced per day after R7	0.01	0.03
SENDAY	proportion of leaf weight senesced per day due to maximum water stress	0.02	0.05

Results using these new parameter values in conjunction with new soil and cultivar files are shown below. Results appear promising, but there are still some open questions, and additional changes to model equations and parameters will be necessary.

Arizona FACE experiments:

Data from 1989 and ambient wet 1991 treatments were used to fit cultivar and ecotype parameters, as well as species coefficients. Data from the ambient dry treatments in 1990 and 1991 were used to fit available soil water and a few other soil parameters. No changes were made using the enhanced CO2 treatments. The CO2 model appears to be working very well without any modifications. It looks like something caused the rate of transition from vegetative to reproductive growth to be a little different between 1989 and the other years—simulated boll weight addition is too fast in 1990 and 1991 with the current set of coefficients. Boll numbers look pretty good in all years. With canopy height fitted to ambient, wet conditions in 1991, it goes too high for 1989, also for ambient, dry conditions in 1991, and for ambient, wet conditions in 1990.

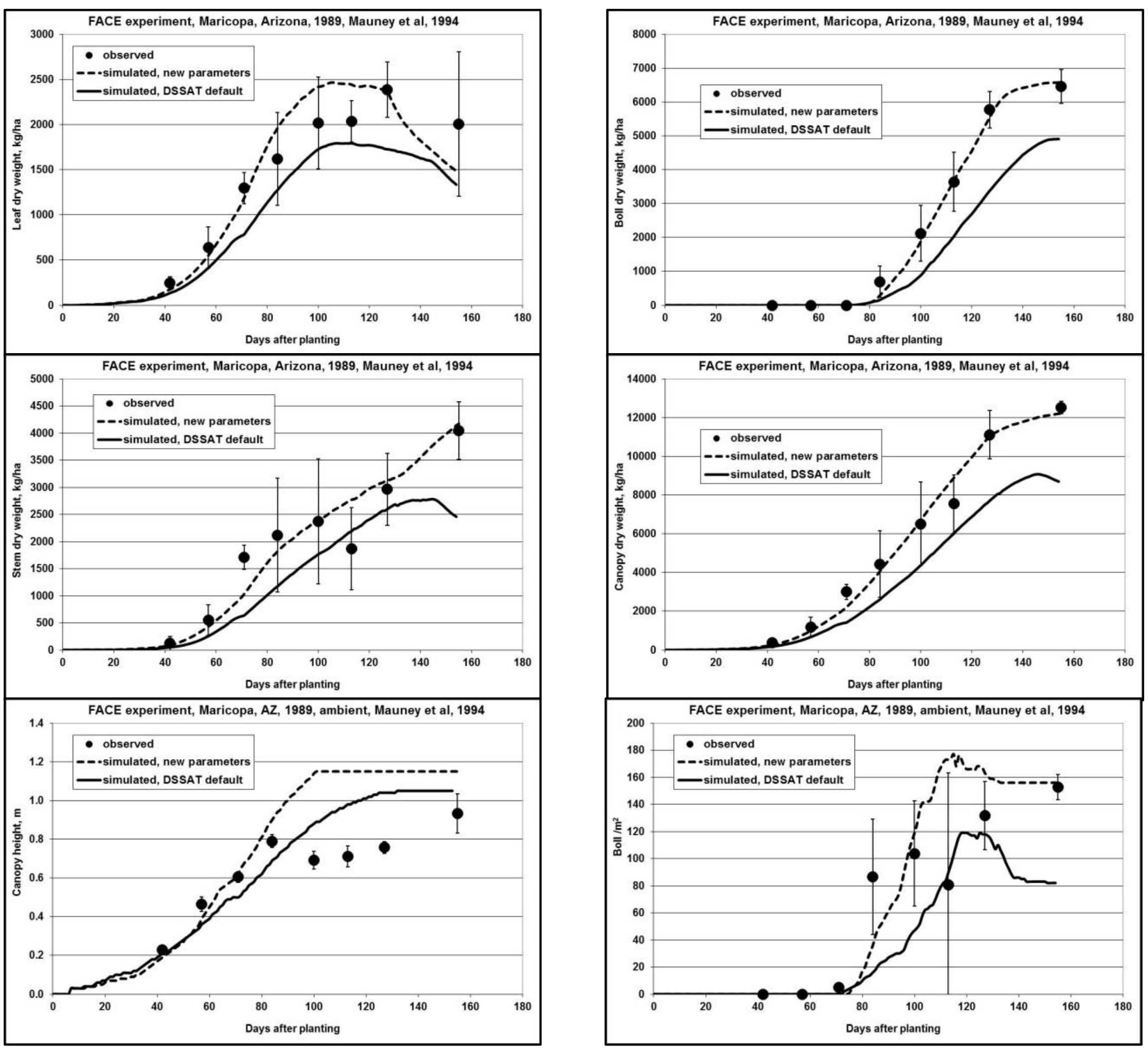


Figure 5. Comparison of simulated and observed leaf, boll, stem, and canopy dry weights for the ambient CO_2 treatment using the default and newly fitted species, soil, and cultivar parameters for the

FACE experiment conducted at Maricopa, AZ in 1989 (Mauney et al., 1992; Kimball et al., 1992; Mauney et al., 1994). Error bars indicate 95% confidence limits for measured values.

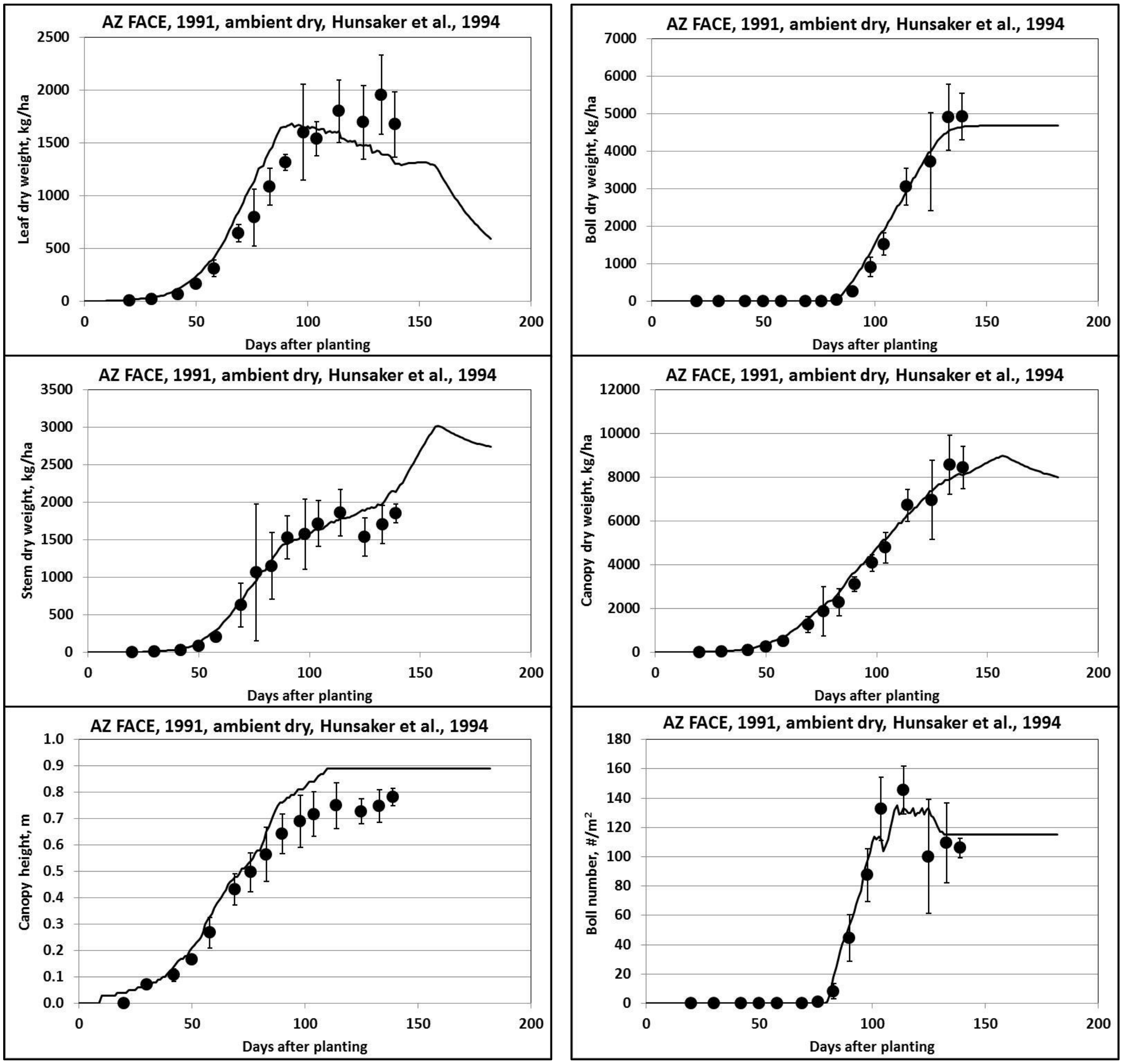


Figure 6. Comparison of simulated and observed leaf, boll, stem, and canopy dry weight, canopy height, and boll number, using newly fitted species, soil, and cultivar parameters for the FACE experiment conducted at Maricopa, AZ in 1991 (Hunsaker et al., 1994; Mauney et al., 1994). Results are for the ambient CO_2, water-stress treatment. Error bars indicate 95% confidence limits for measured values.

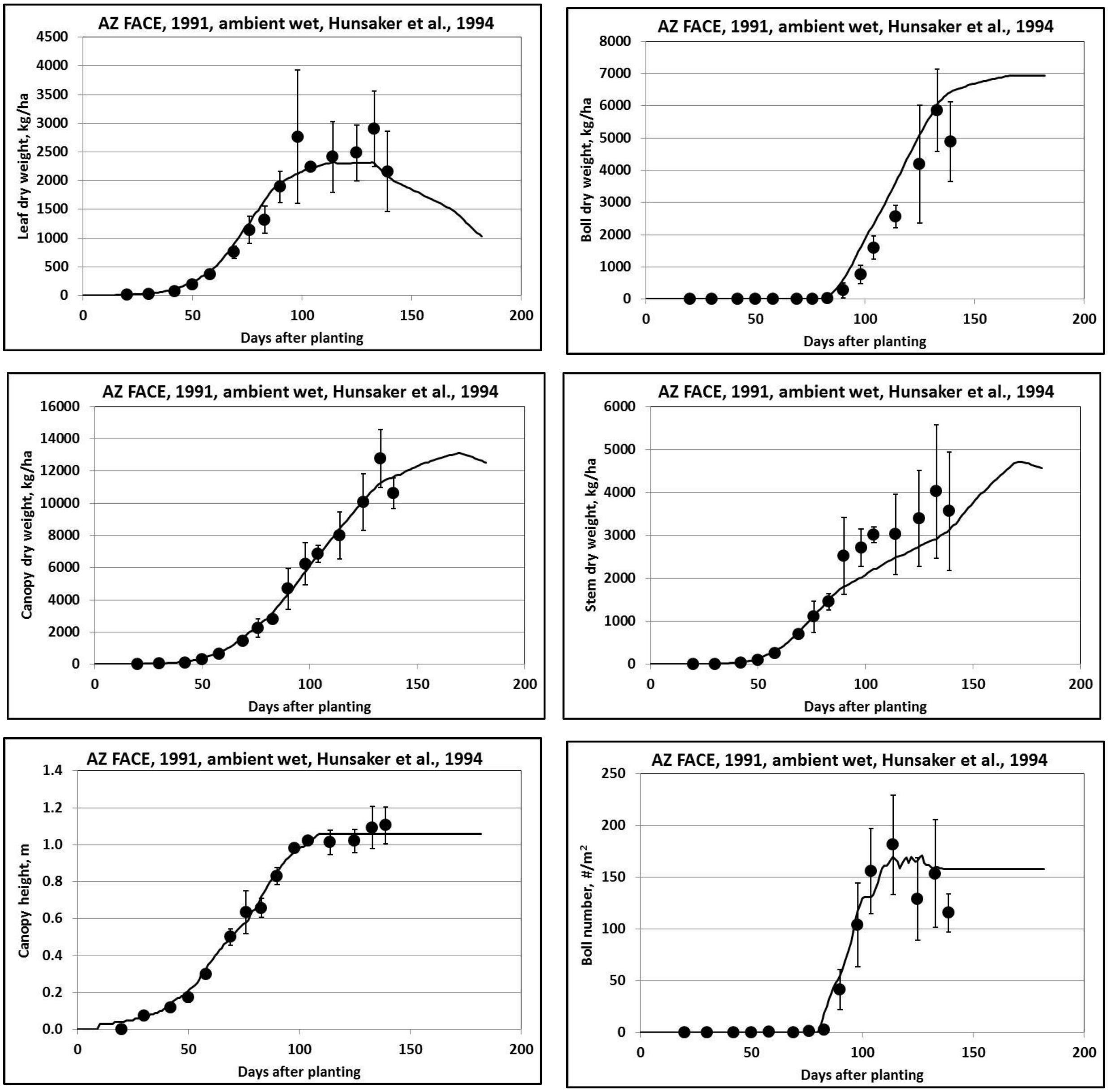


Figure 7. Comparison of simulated and observed leaf, boll, stem, and canopy dry weight, canopy height, and boll number for the FACE experiment conducted at Maricopa, AZ in 1991 (Hunsaker et al., 1994; Mauney et al., 1994). Results are for the ambient CO_2, well-irrigated treatment. Error bars indicate 95% confidence limits for measured values.

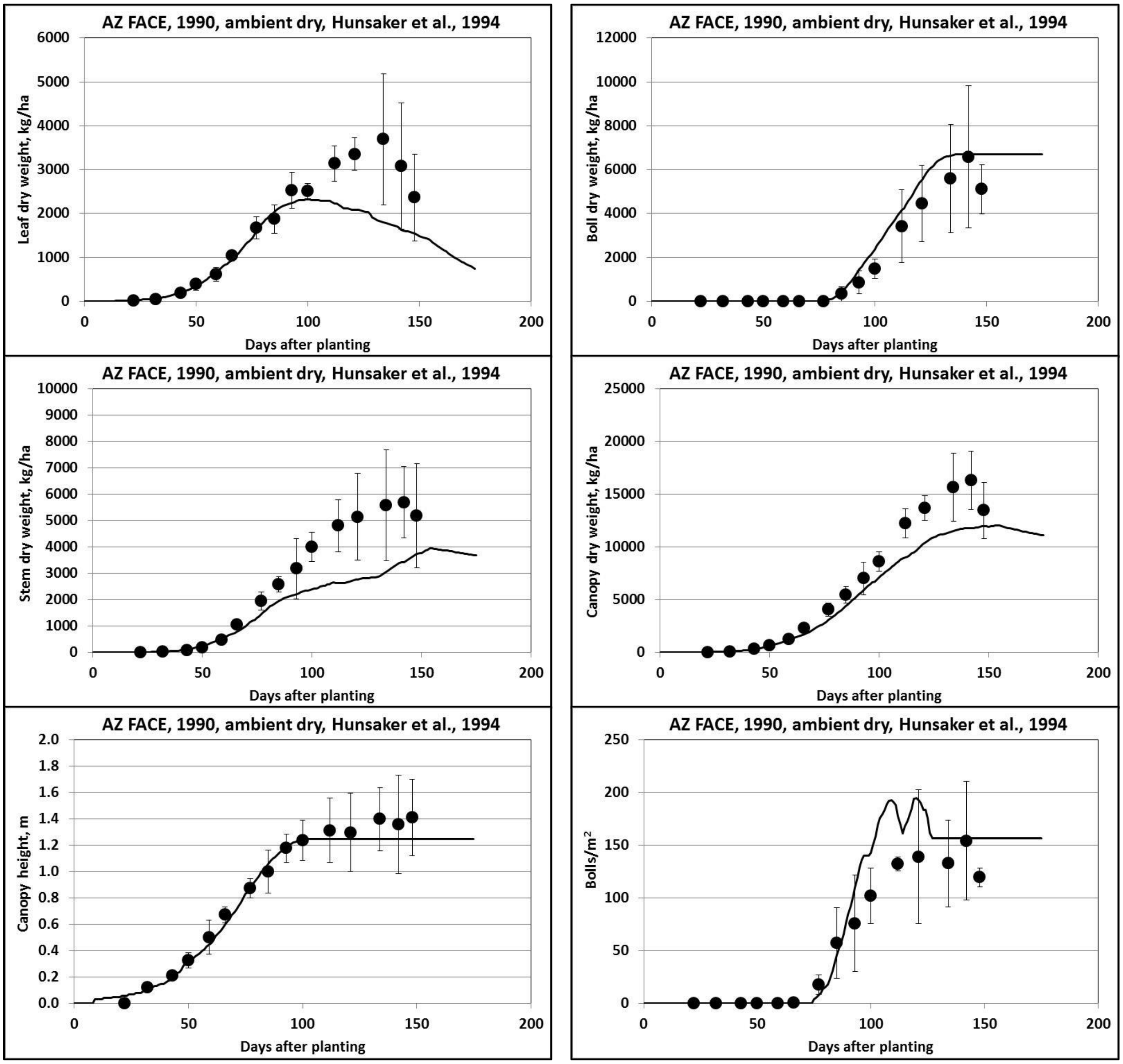


Figure 8. Comparison of simulated and observed leaf, boll, stem, and canopy dry weight, canopy height, and boll number for the FACE experiment conducted at Maricopa, AZ in 1990 (Hunsaker et al., 1994; Mauney et al., 1994). Results are for the ambient CO_2, water-stress treatment. Error bars indicate 95% confidence limits for measured values.

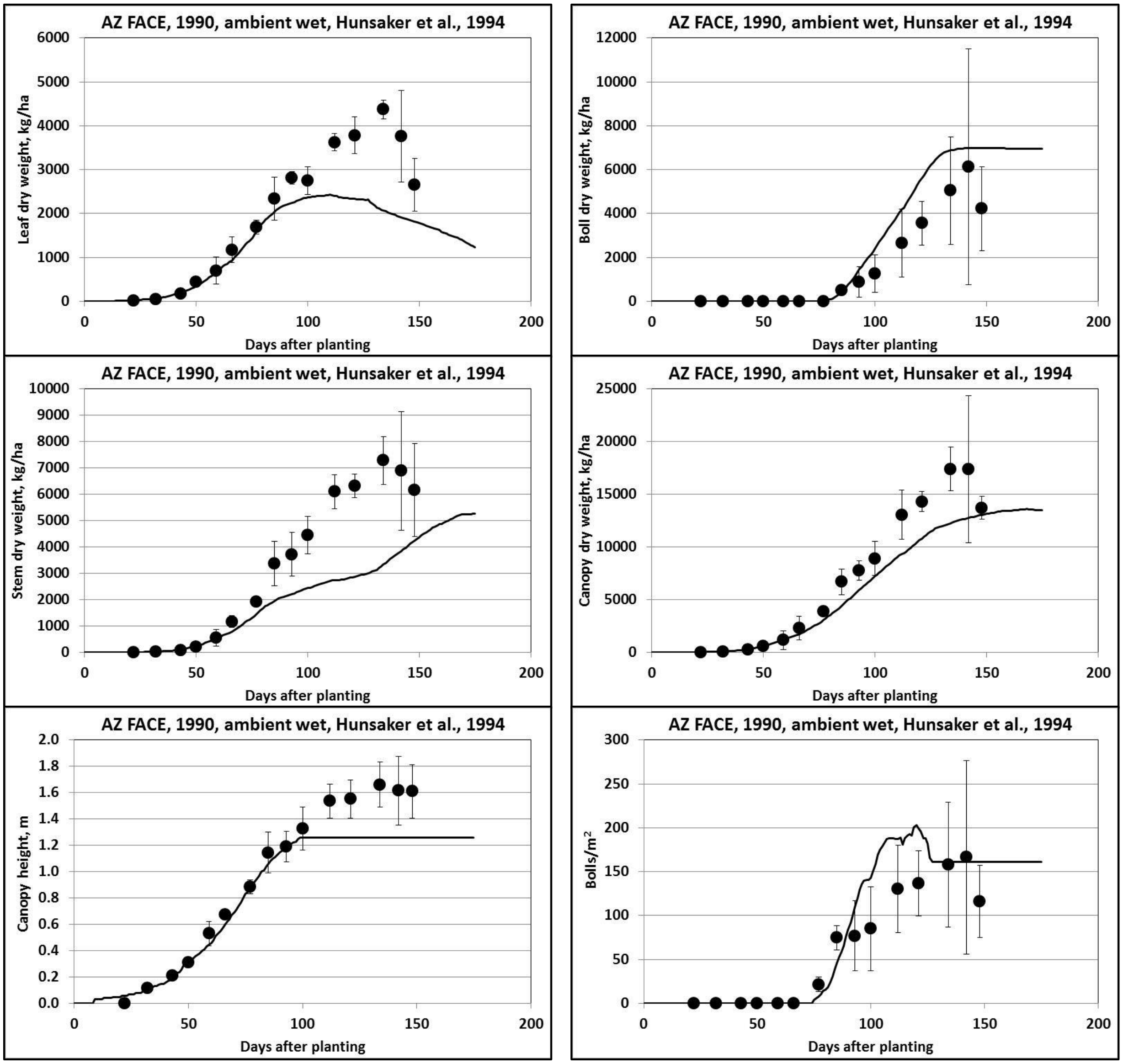


Figure 9. Comparison of simulated and observed leaf, boll, stem, and canopy dry weight, canopy height, and boll number for the FACE experiment conducted at Maricopa, AZ in 1990 (Hunsaker et al., 1994; Mauney et al., 1994). Results are for the ambient CO_2, well-irrigated treatment. Error bars indicate 95% confidence limits for measured values.

Arizona AgIIS experiment:

For this experiment, N and irrigation application amounts and timing varied slightly among replications for each treatment. Therefore, treatments were created for each individual replication, as well as for treatment averages. Results shown in the graphs below are for treatment averages only. We modified cultivar coefficients for this experiment, necessitated by changes in the species file. We also increased available soil water in soil layers below 30 cm, raised the soil drainage factor (SLDR) from 0.2 to 0.5, and reduced the runoff curve number from 80 to 76. This provided more water for crop growth, particularly late in the season. Simulated leaf and stem weights were slightly low for the optimal N treatments during mid-season, but in general, simulated values for all variables fell within the 95% confidence intervals of observed values.

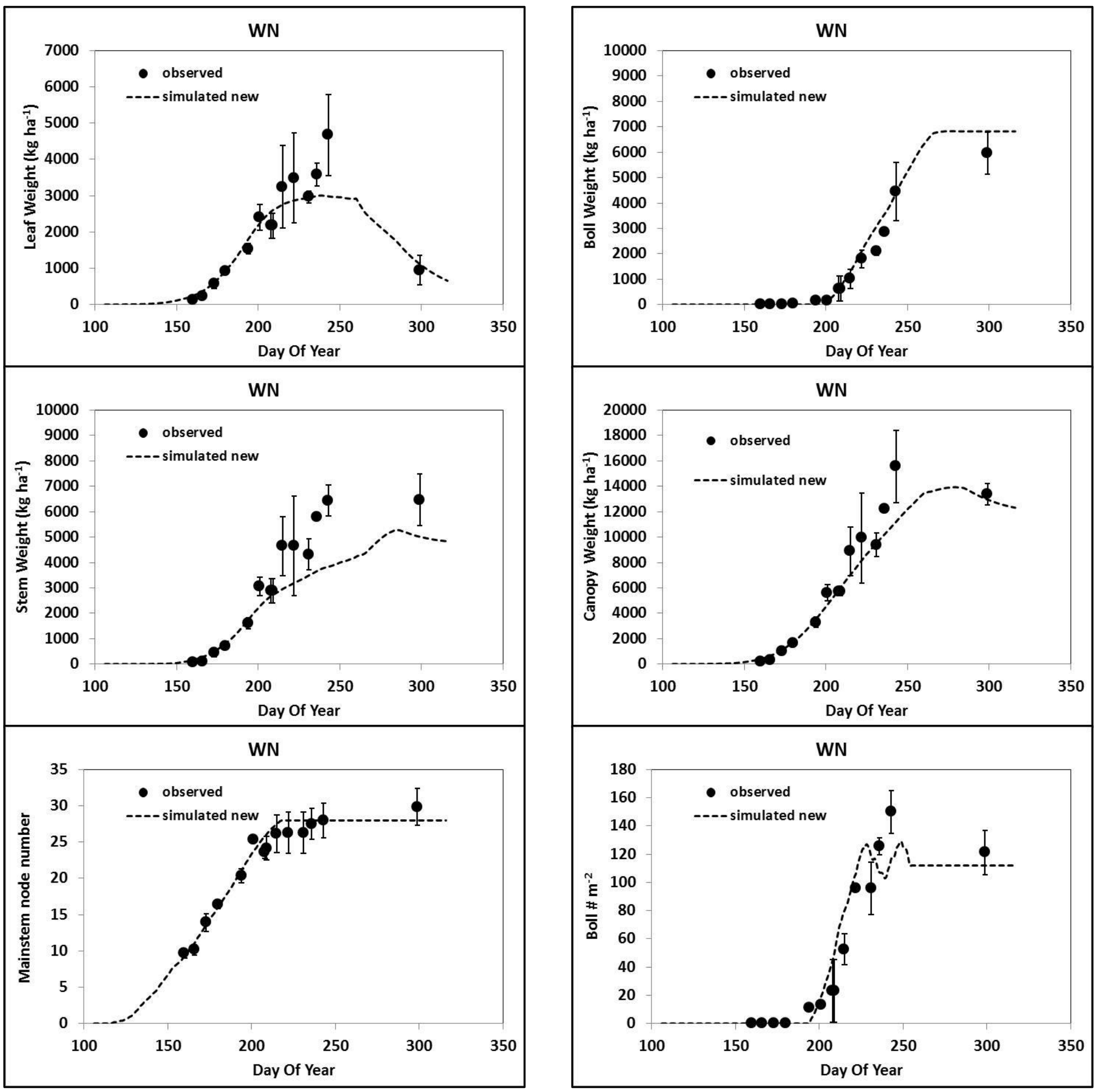


Figure 10. Comparison of simulated and observed leaf, boll, stem, and canopy dry weight, mainstem node number, and boll number for the AgIIS experiment conducted at Maricopa, AZ in 1999 (El-Shikha et al., 2008). Results are for the optimal water and optimal N treatment. Error bars indicate 95% confidence limits for measured values.

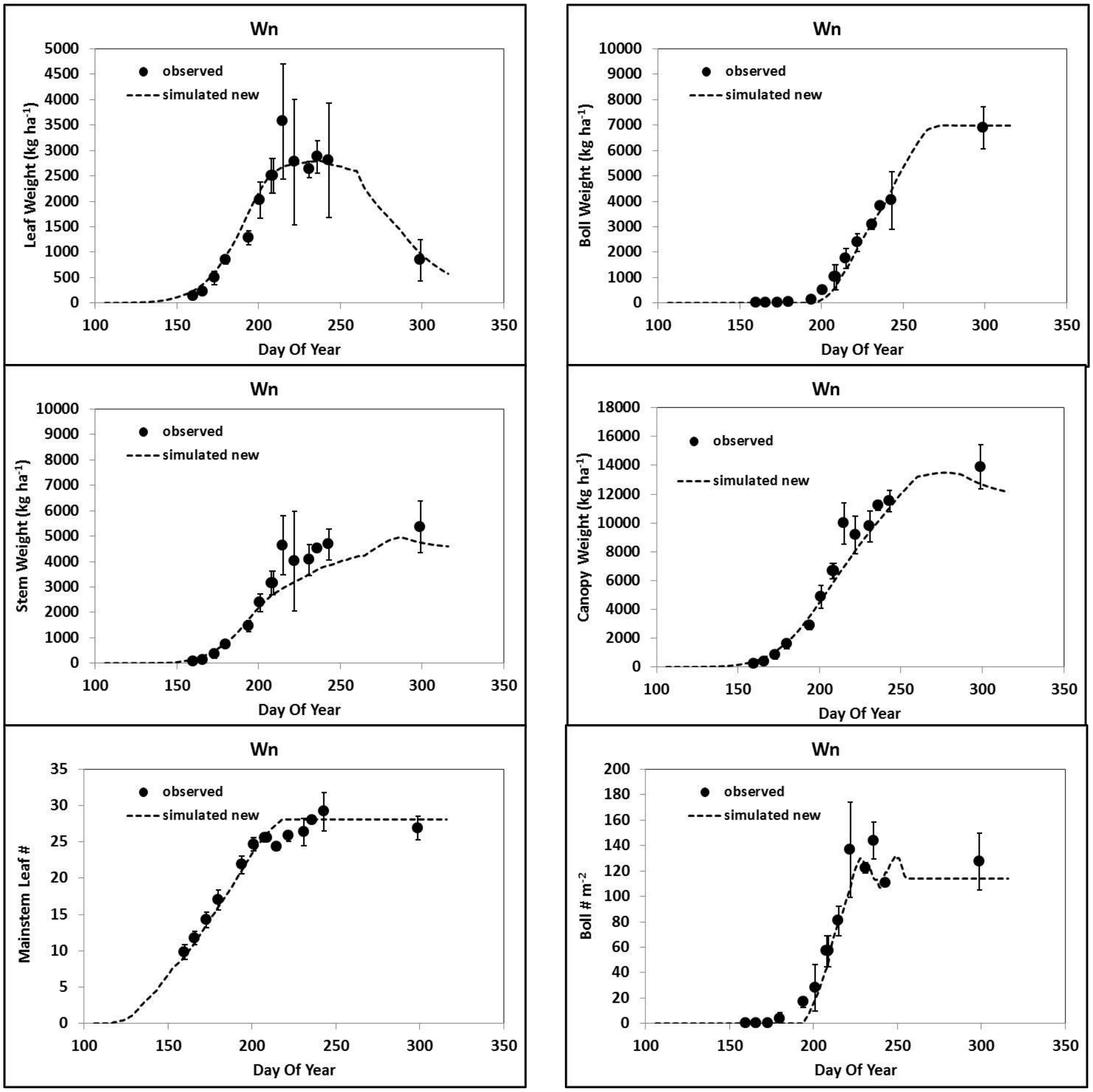


Figure 11. Comparison of simulated and observed leaf, boll, stem, and canopy dry weight, mainstem node number, and boll number for the AgIIS experiment conducted at Maricopa, AZ in 1999 (El-Shikha et al., 2008). Results are for the optimal water and low N treatment. Error bars indicate 95% confidence limits for measured values.

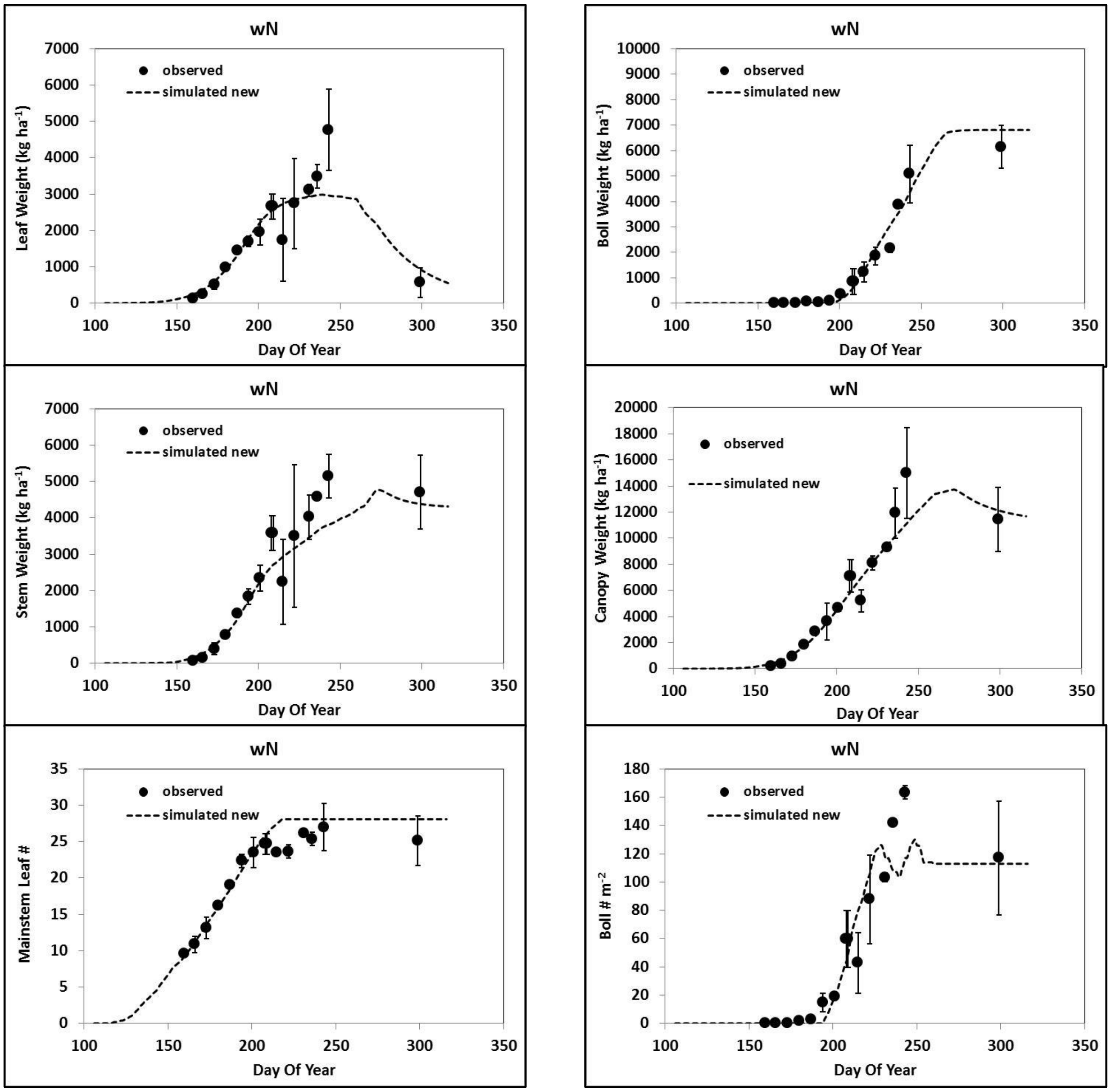


Figure 12. Comparison of simulated and observed leaf, boll, stem, and canopy dry weight, mainstem node number, and boll number for the AgIIS experiment conducted at Maricopa, AZ in 1999 (El-Shikha et al., 2008). Results are for the low water and optimal N treatment. Error bars indicate 95% confidence limits for measured values.

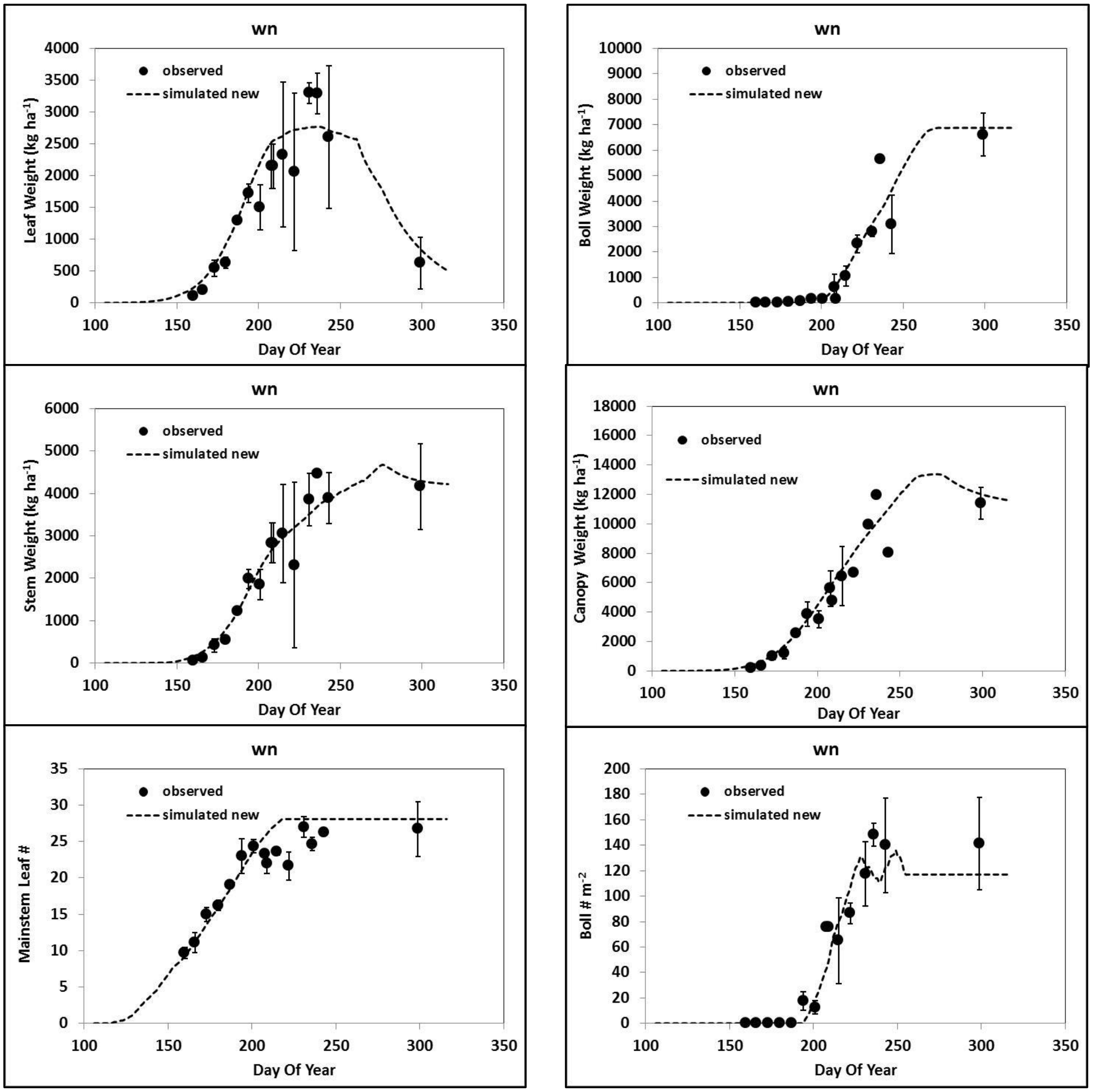


Figure 13. Comparison of simulated and observed leaf, boll, stem, and canopy dry weight, mainstem node number, and boll number for the AgIIS experiment conducted at Maricopa, AZ in 1999 (El-Shikha et al., 2008). Results are for the low water and low N treatment. Error bars indicate 95% confidence limits for measured values.

Arizona FISE experiment:

In this experiment, seeds were planted into a dry seedbed, then irrigated to promote emergence about a week later. With the cultivar coefficient PL-EM (thermal days between planting and emergence) set to a reasonable value, emergence occurred too early if planting was set for the actual date, since simulated emergence occurred regardless of soil moisture level in the upper soil layer. We therefore set planting to occur on the first irrigation date. A comparison of simulated and observed canopy height and width is shown in Figure 14 for the typical density (11.6 plants m^{-2}) and low and high N treatments in 2002. Results for the sparse density (5.3 plants m^{-2}) treatments were similar and are not shown. For the dense treatments (21.1 plants m^{-2}), achieved through planting in twin rows spaced 0.2 m apart, simulated canopy height was higher than observed for both high and low N treatments, and simulated canopy width was too low early in the season (Figure 15). This was likely due to the model not having the capability to simulate twin rows. Simulated final canopy height was higher than observed for all low N treatments. Both observed and simulated yields were slightly higher for low N treatments than for high N treatments in 2002 (Figure 16).

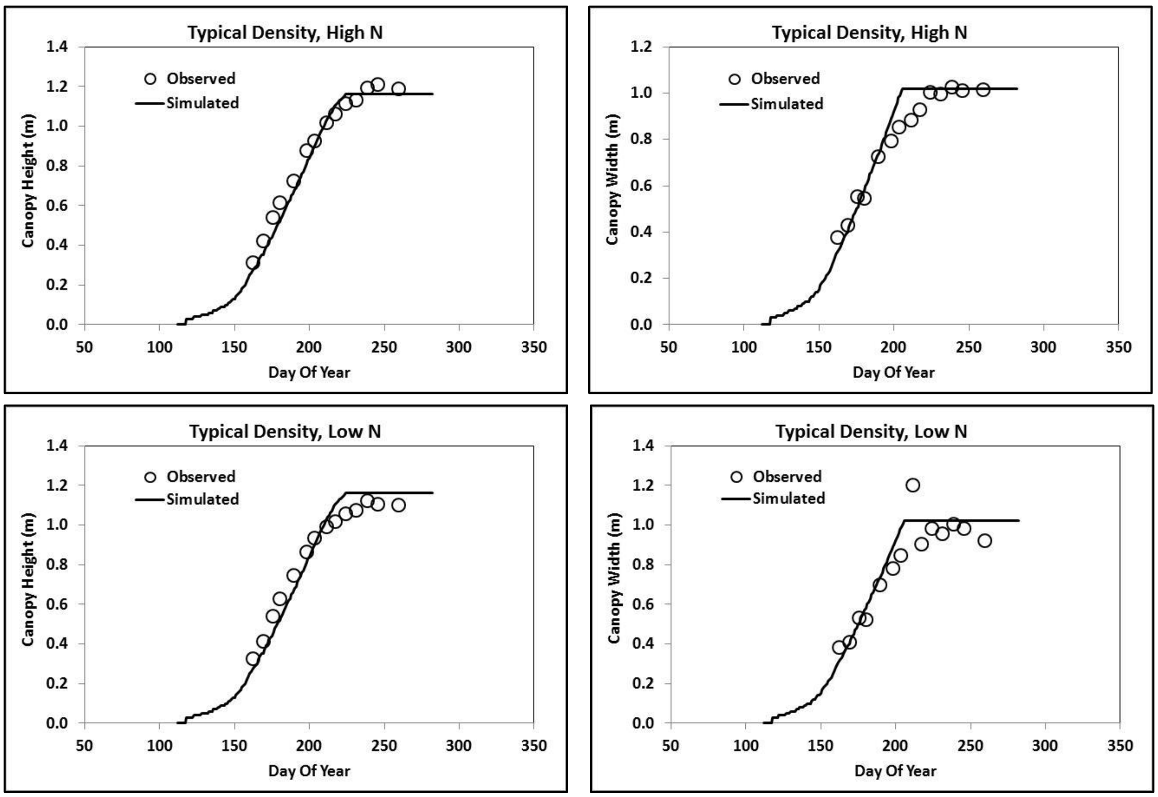


Figure 14. Comparison of simulated and observed canopy height and width for the FICE experiment conducted at Maricopa, AZ in 2002 (Hunsaker et al., 2005). Results are for the typical density and high and low N treatments.

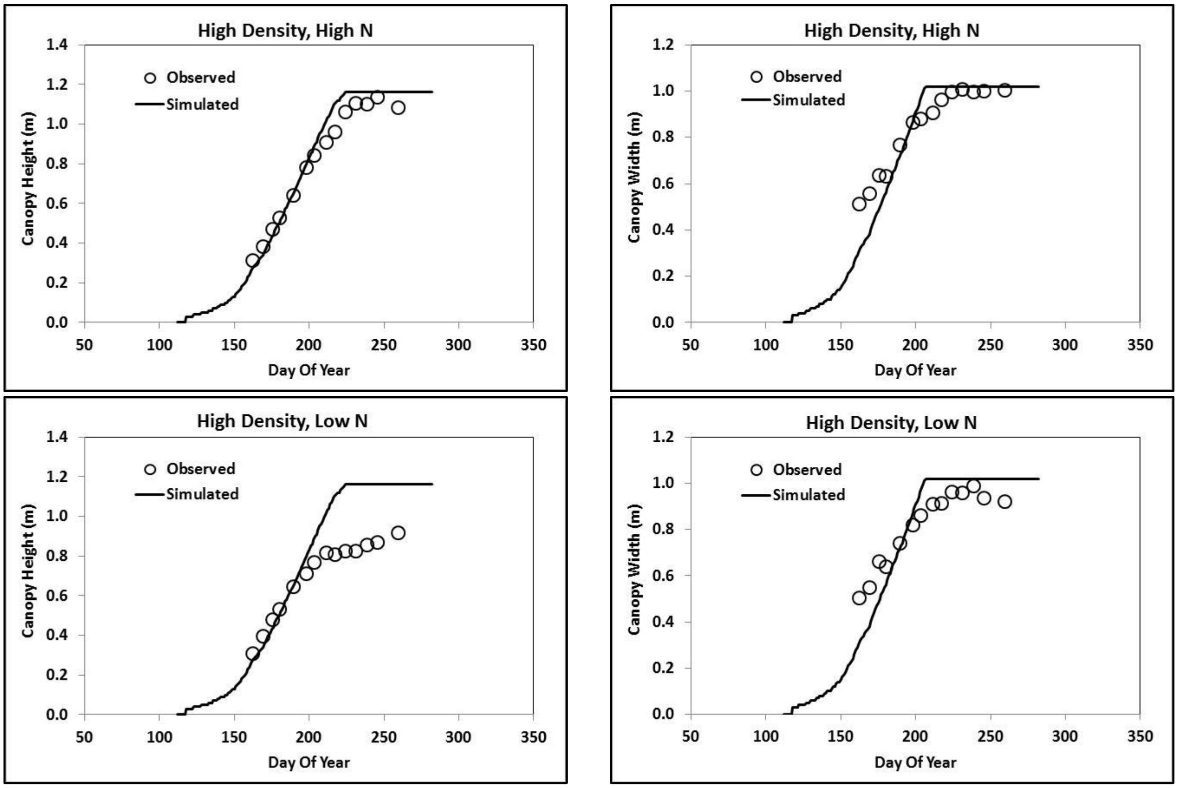


Figure 15. Comparison of simulated and observed canopy height and width for the FICE experiment conducted at Maricopa, AZ in 2002 (Hunsaker et al., 2005). Results are for the high density and high and low N treatments.

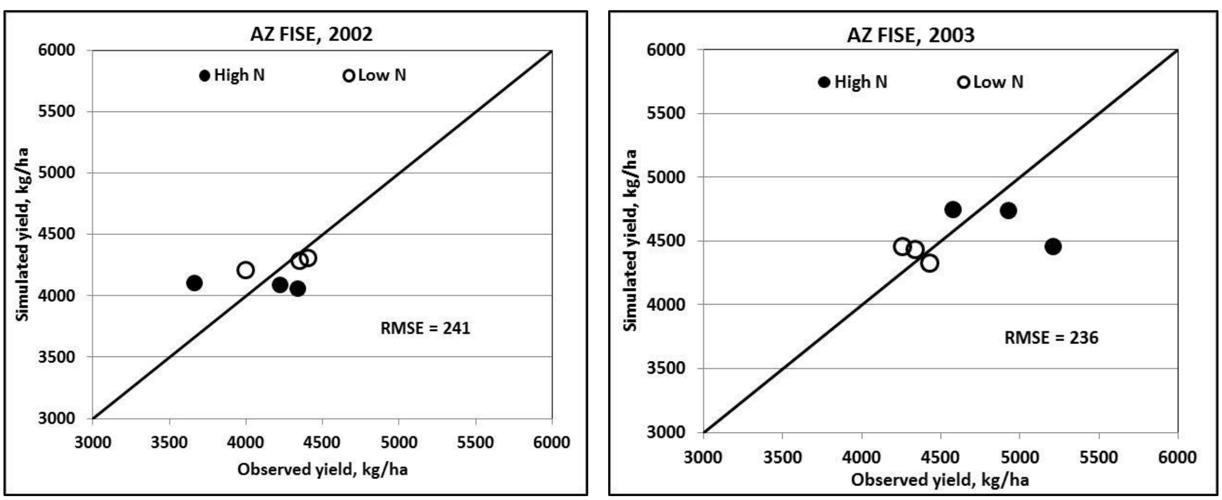


Figure 16. Comparison of simulated and observed seed cotton dry weight for the FICE experiment conducted at Maricopa, AZ in 2002 and 2003 (Hunsaker et al., 2005).

In 2003, the relationship of simulated to observed canopy height and width was similar to that in 2002. Simulated height matched observed height well for both typical and low plant populations in high N treatments, but final height was somewhat high for low N treatments (Figure 17). Canopy weight was measured throughout the season in 2003, and simulated weights matched observed weights well until midseason, when simulated weight was too low (Figure 18). In 2003, both observed and simulated yields were slightly higher for high N treatments than for low N ones (Figure 16).

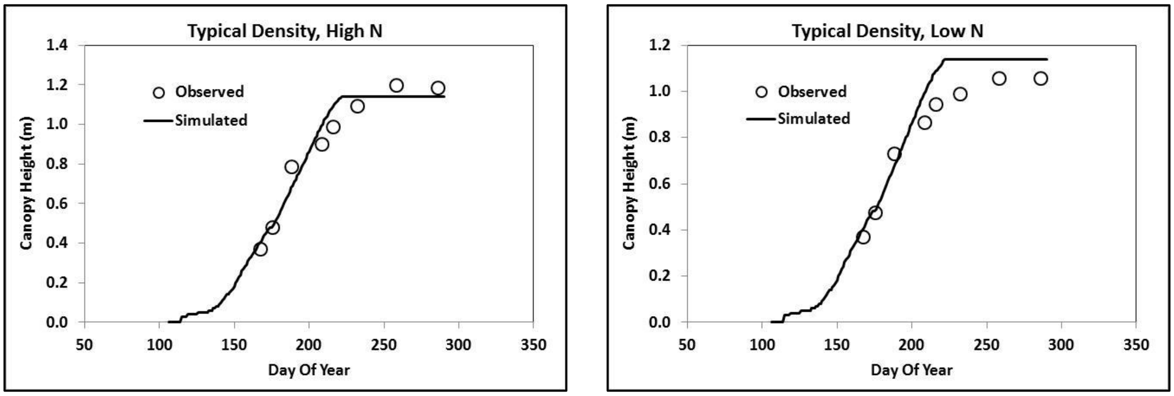


Figure 17. Comparison of simulated and observed canopy height for the FICE experiment conducted at Maricopa, AZ in 2003 (Hunsaker et al., 2005). Results are for the typical density and high and low N treatments.

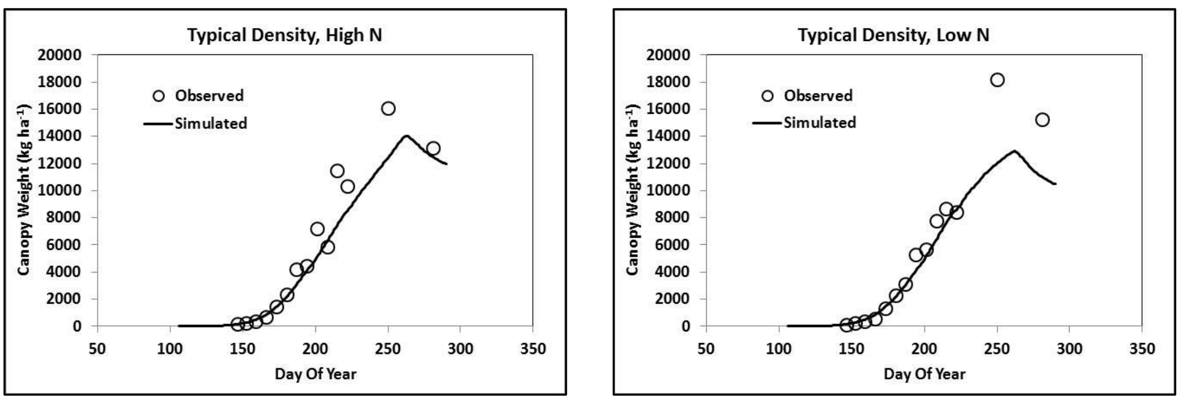


Figure 18. Comparison of simulated and observed canopy weight for the FICE experiment conducted at Maricopa, AZ in 2003 (Hunsaker et al., 2005). Results are for the typical density and high and low N treatments.

Texas root growth and soil water extraction study:

In this experiment performed in Temple, TX in 1984, there was only one treatment. Measurements consisted of LAI, and root length densities and soil water contents at 10 depths. With the values contained in the species file that were based on data from AZ and NC, we were not able to fit root length densities observed in this experiment. We modified several soil parameters in order to match measured soil water content highs and lows in each layer. Figure 19 compares estimated and simulated LAI throughout the season. Figure 20 compares observed and simulated soil water content in selected layers, and Figure 21 shows observed and simulated root length density for these same layers.

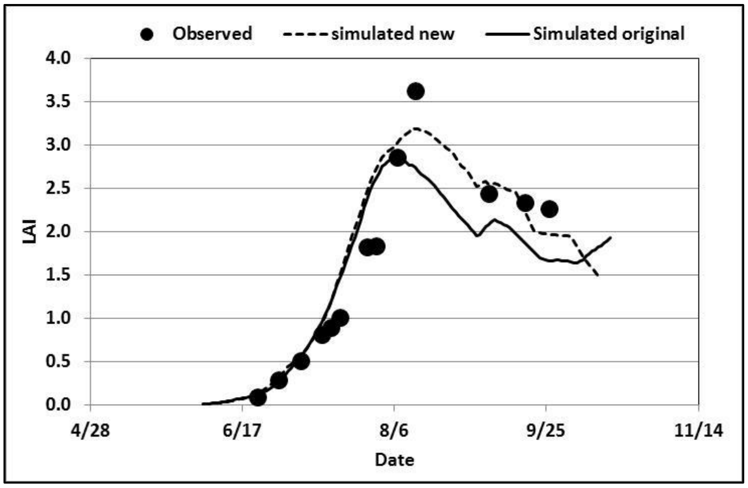


Figure 19. Comparison of simulated and estimated LAI for the experiment conducted at Temple, TX in 1984 (Bland and Dugas, 1989). Simulated original values were obtained using CROPGRO-Cotton Version 4.6 with the original species, soil, and cultivar files included with the release.

Figure 20 compares observed and simulated soil water content in selected layers, and Figure 21 shows observed and simulated root length density for selected layers. Increasing the maximum fraction of water that could drain per day (SLDR) from 0.3 to 0.7 allowed simulated water content to fall in upper layers and rise in lower layers after rainfall or irrigation more as indicated by measured values. Reducing root length per unit weight (RFAC1) in the species file from the original value of 12,000 to 10,000 cm g^{-1} reduced root length volume too much for this experiment, but resulted in better root and canopy growth in most other experiments.

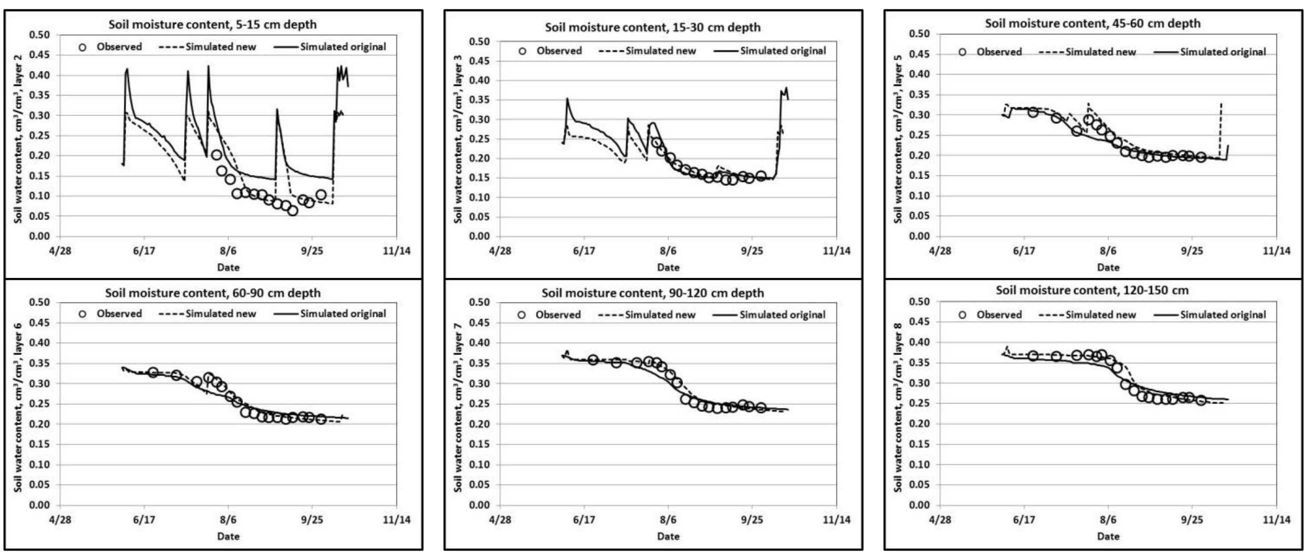


Figure 20. Comparison of simulated and observed soil water content for selected soil layers for the experiment conducted at Temple, TX in 1984 (Bland and Dugas, 1989). Simulated original values were obtained using CROPGRO-Cotton Version 4.6 with the original species, soil, and cultivar files included with the release.

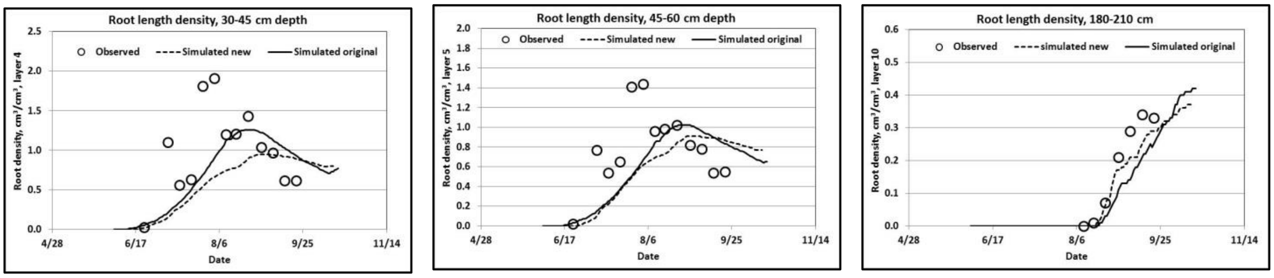


Figure 21. Comparison of simulated and observed root length density for selected soil layers for the experiment conducted at Temple, TX in 1984 (Bland and Dugas, 1989). Simulated original values were obtained using CROPGRO-Cotton Version 4.6 with the original species, soil, and cultivar files included with the release.

Texas irrigation timing experiment:

There was some discrepancy between the irrigations specified in the original data files and the irrigation totals specified in the paper by Bordovsky et al. (2015). Initial soil water was at field capacity to 0.6 m after initial irrigations according to Bordovsky et al. Initial soil water on the simulation start date (1 January) was set to 0.18 cm^3 cm^{-3} for all four years, and this along with the specified irrigation amounts at the start of the season did result in soil moisture being at roughly field capacity to 0.6 m at the time of planting. For 2013, initial soil water was increased to field capacity at the start of simulation on 1 January in the top 5 layers (to 0.6 m), and this improved fit (Figure 22). This increased yields to better match observed yields this year (RMSE improved substantially). Using Version 4.7, a better fit was obtained for 2010 if initial soil water was set to 0.17 in all layers. There was no real justification in papers or weather files for making these changes for 2010 and 2013. There does appear to be about an inch difference in irrigation before and at planting for 2013 according to irrigation file and paper by Bordovsky et al. (2015).

Simulated rooting depth increase stops if soil water is at or below the wilting point in lower layers. This happened in simulations of all years after 2010. It took a while to figure out why rooting depth was not determined by SRGF in the soil profile. SRGF was set to allow rooting in all layers to 2.1 m depth, yet maximum simulated rooting depth was 0.63, 1.01, and 1.66 m in 2011, 2012, and 2013, respectively. This is related to choosing option S for MESEV (using the Suleiman-Ritchie soil evaporation method). This routine allows bare soil ET to pull water all the way from the bottom of the profile, even below the wilting point. I'm not convinced that soil water should ever drop below the wilting point in these lower layers. In the model, soil evaporation moves water up from all layers, even 2.1 m down, prior to planting, when simulation starts on 1 January. It seems like there should be a limit on this to just the top 20-30 cm. I decided to leave initial soil water low enough for this to happen primarily because having these different rooting depths gave such good fit to the data, and there was very little rainfall to fill up the lower layers of the soil profile during the winter each year. So maybe soil water didn't get below the wilting point, but maybe it got down to the wilting point at the end of one growing season, with insufficient precipitation in the winter, or irrigation, to fill these lower layers back up. Simulated yields matched observed yields better using option S for MESEV rather than option R (Ritchie-Ceres soil evaporation method). Maximum simulated rooting depth using MESEV=R reached 2.1 m in all years, since this model does not allow water to be pulled from the lower layers through evaporation. Setting initial soil water to the wilting point in lower layers would have stopped root growth into these lower layers. Another way to deal with this problem might have been to use ending values for soil moisture in one year to initialize soil moisture the next year, since treatment locations were unchanged from year to year.

It can create problems when things like tillage and soil analysis occur months before planting, and are specified in input files. The start date for simulation must be before any date specified for any operation. Initial soil water cannot just be set to field capacity at planting, as might have been desirable for this experiment. Tillage routines were turned off when using Version 4.7 since tillage implement depth minimum was set to 10 cm, and the depth specified by the researcher was 5 cm. Version 4.7 would not run with this discrepancy.

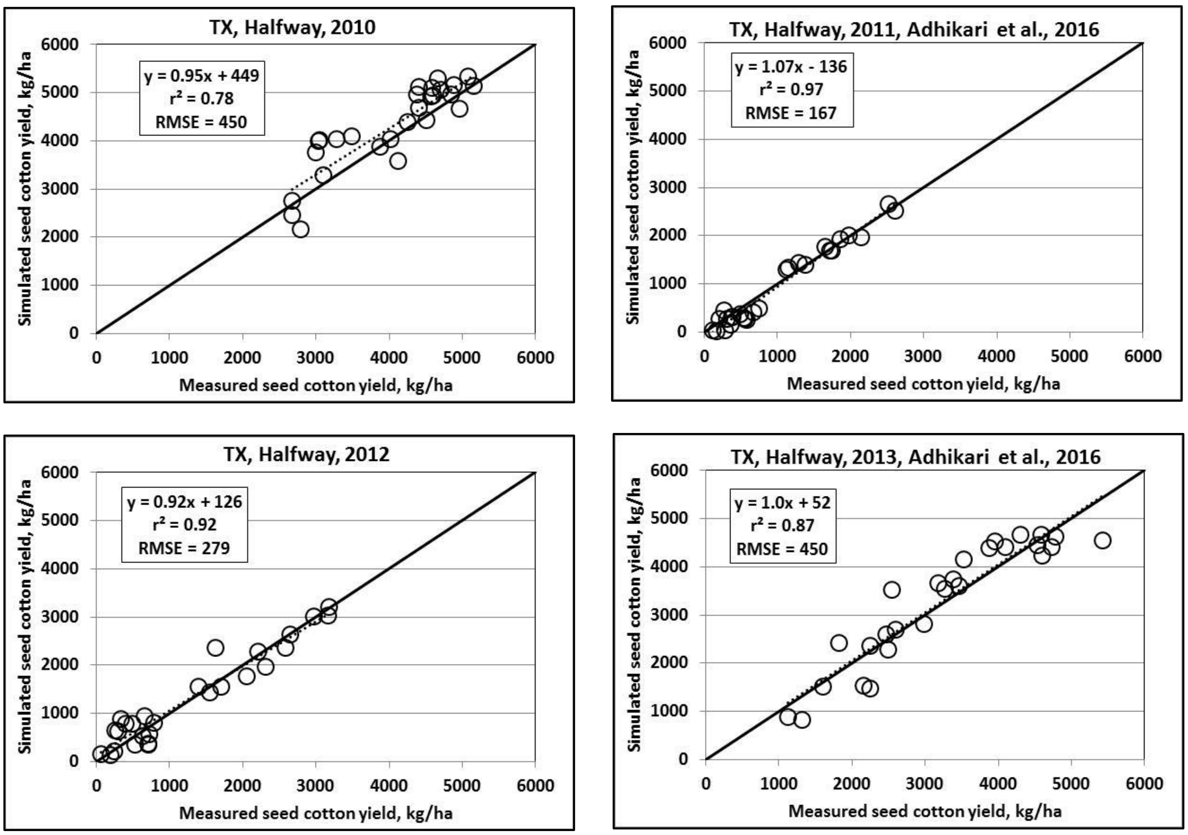


Figure 22. Comparison of simulated and observed seed cotton yield for 2010-2013 for the irrigation experiments conducted in Halfway, TX (Bordovsky et al., 2015; Adhikari et al., 2016).

Texas deficit irrigation experiment:

We modified the irrigation schedule prior to start of the different irrigation treatments to match information contained in the paper by Modala et al., 2015). A comparison of simulated to observed canopy height is shown in Figure 23, and a comparison of simulated to observed LAI is shown in Figure 24. It appears that LAI increase stops too soon for all treatments. Simulated yields matched observed yields well, with a RMSE of 228 kg ha^{-1}.

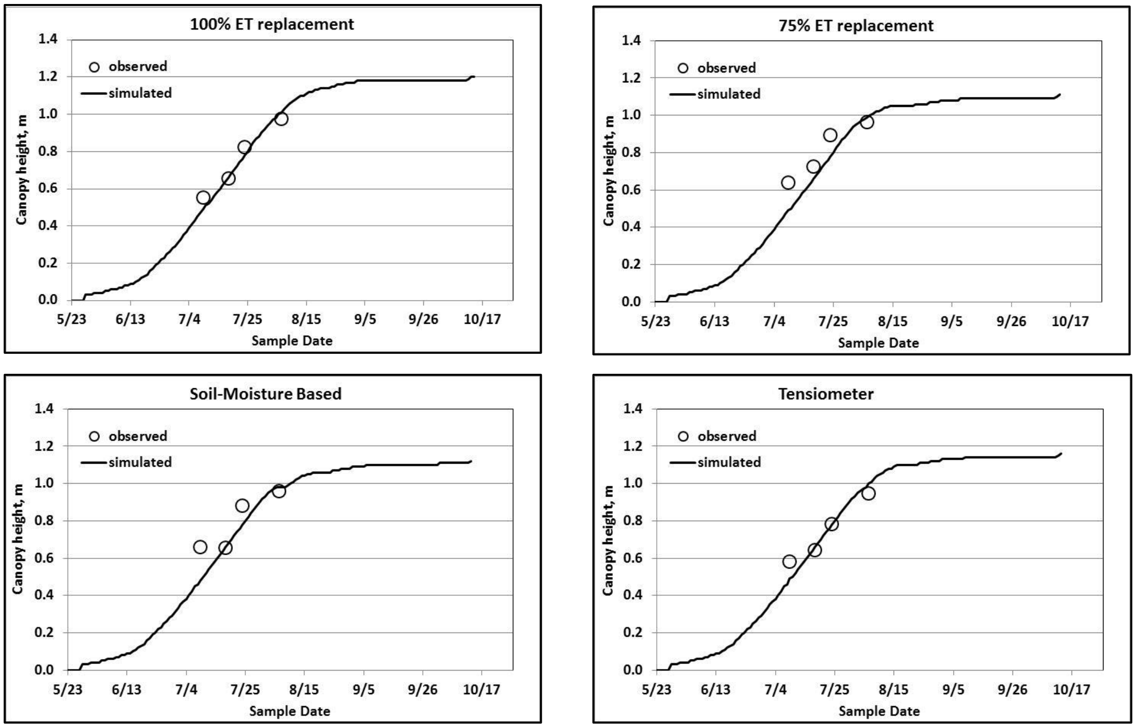


Figure 23. Comparison of simulated and observed canopy height for the deficit irrigation experiment conducted at the Chillicothe Research Station in 2012 (Modala et al., 2015).

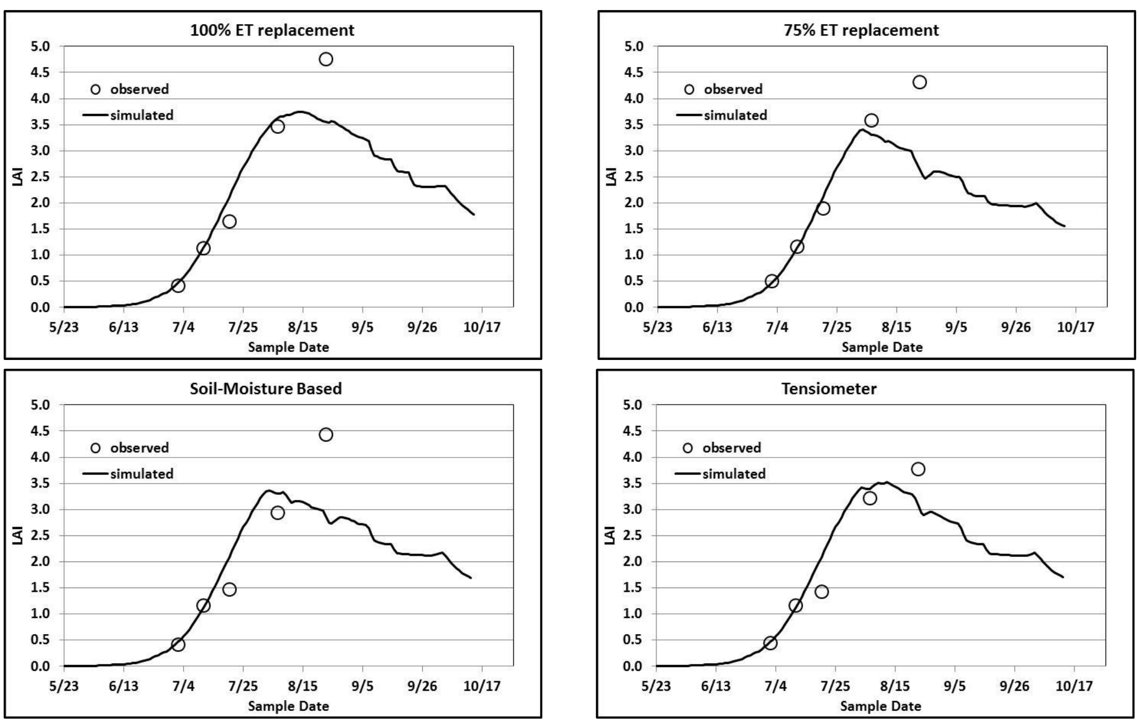


Figure 24. Comparison of simulated and observed leaf area index (LAI) for the deficit irrigation experiment conducted at the Chillicothe Research Station in 2012 (Modala et al., 2015).

Texas cover crop impact study:

This experiment recorded soil moisture at multiple depths from 2013-2015 for dryland and irrigated treatments grown after a winter wheat cover crop and without a cover crop. Data from 2013 were used to determine drained upper limit (DUL) and lower limit (LL) for each soil layer for each treatment. Perhaps because of calibration differences, it appeared that different values were needed for the different treatments, so four different soil profiles were created. We created soil moisture initialization files for each year/cover crop/irritation treatment using soil water measurements made on the simulation start date for the year. We used MESEV=R in these simulations, since if we used the Suleiman-Ritchie soil evaporation routine, soil moisture decreased in lower layers before roots entered the layers, and the data did not indicate that this actually happened. Figures 25-28 show a subset of comparisons of simulated to observed soil moisture in different layers. Note that there are some times during the season when water in the 20-40 cm depth appears to rise more after a rainfall than it should. In general, simulated soil moisture values matched observed values well across seasons for all treatments and soil layers.

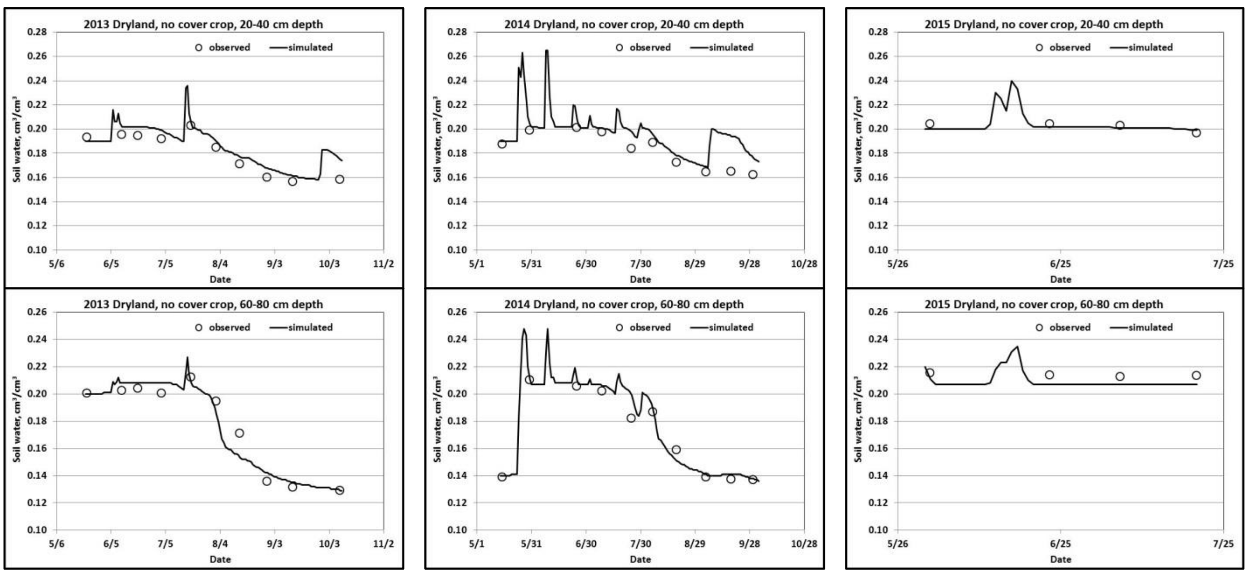


Figure 25. Comparison of simulated and observed soil moisture at 20-40 cm depth and 60-80 cm depth for the dryland, no cover crop treatment for 2013-2015.

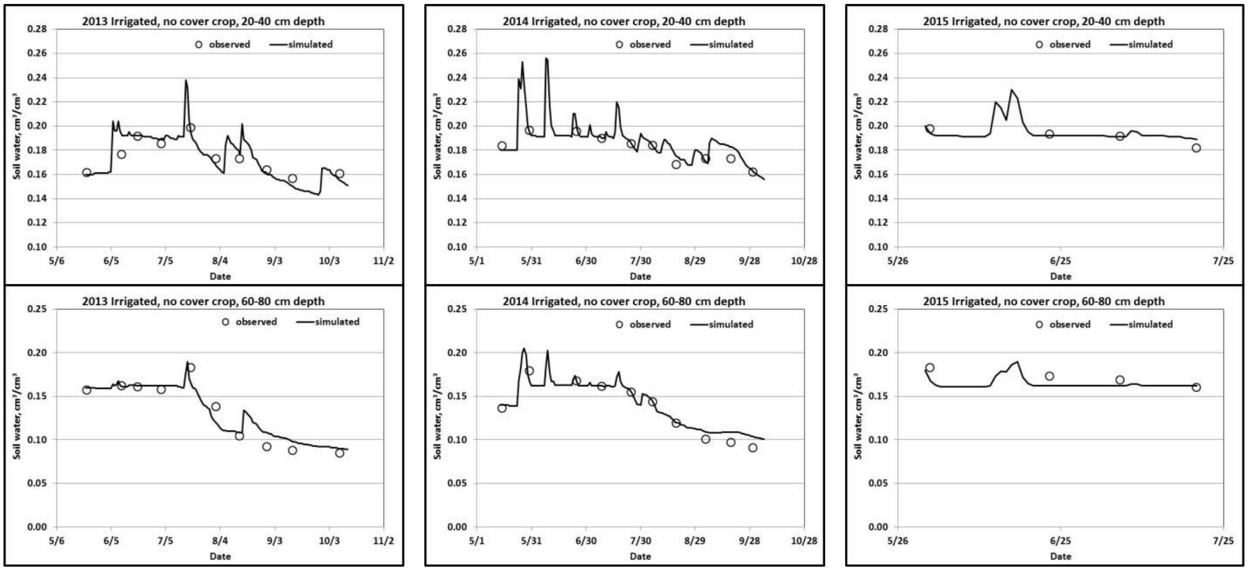


Figure 26. Comparison of simulated and observed soil moisture at 20-40 cm depth and 60-80 cm depth for the irrigated, no cover crop treatment for 2013-2015.

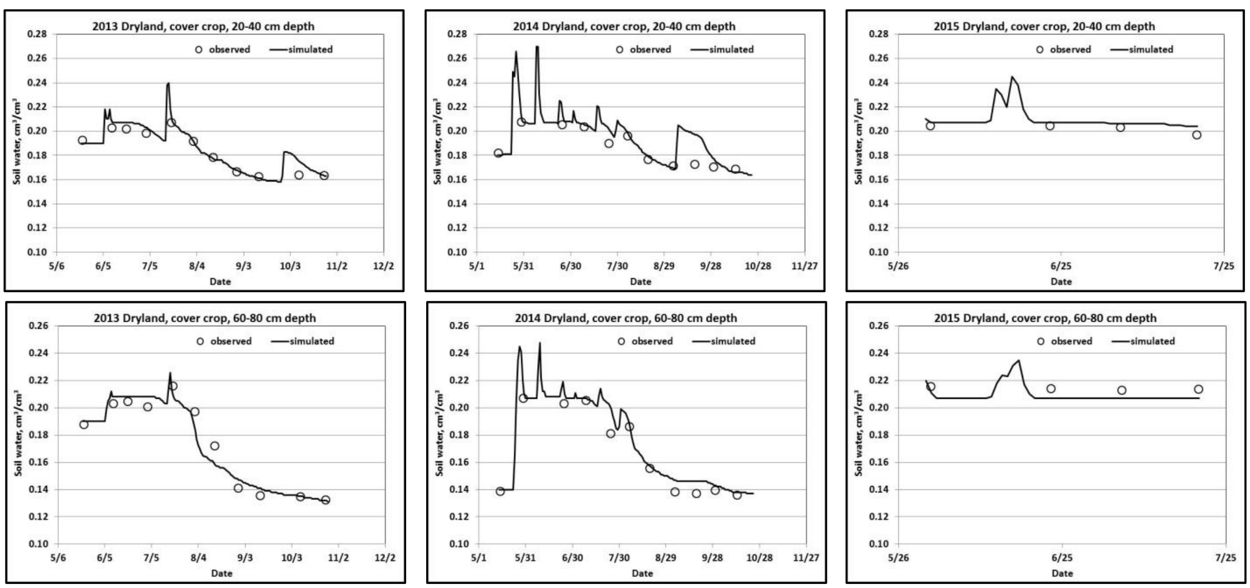


Figure 27. Comparison of simulated and observed soil moisture at 20-40 cm depth and 60-80 cm depth for the dryland, wheat cover crop treatment for 2013-2015.

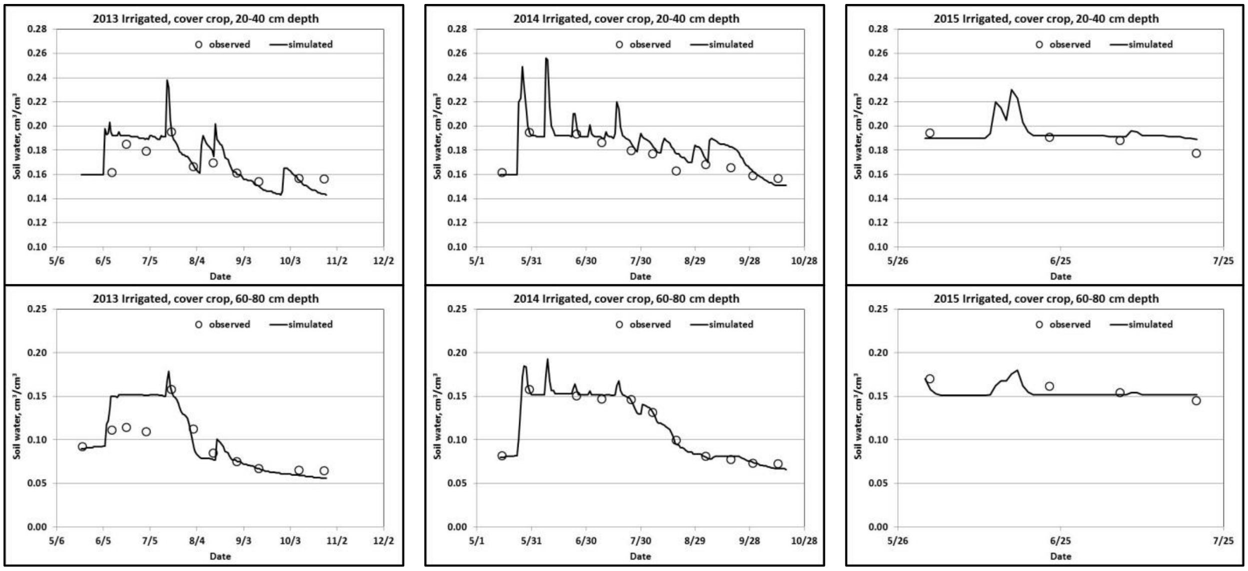


Figure 28. Comparison of simulated and observed soil moisture at 20-40 cm depth and 60-80 cm depth for the irrigated, wheat cover crop treatment for 2013-2015.

Georgia irrigation study:

Once we modified canopy weight values in the original data files so that canopy weight = leaf + stem + boll, we modified soil profile parameters and cultivar coefficients to yield a better fit between simulated and observed values for canopy height; leaf area; and leaf, stem, boll, seed cotton, and canopy dry weight. Cultivar parameters were modified based on the irrigated treatment. Soil profile parameters were modified based on the rainfed treatment. Soil water content was increased in each layer so that available soil water equaled the average for this soil according to USDA-NRCS (2017). In general, simulated values match observed values well. However, simulated stem weight appeared to be low for both treatments. No information was available to calculate confidence intervals for observed data. Comparisons of simulated and observed leaf, boll, seed cotton, and canopy weights for irrigated and rainfed treatments are shown in Figure 29.

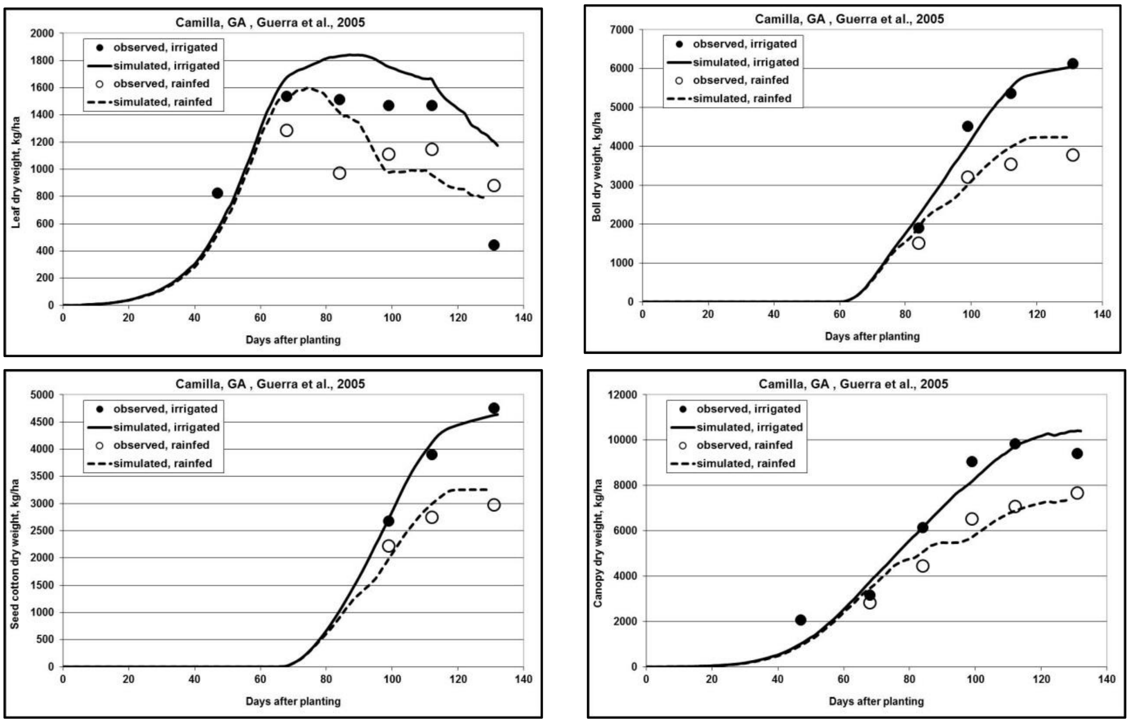


Figure 29. Comparison of simulated and observed leaf, boll, seed cotton, and canopy dry weights for irrigated and rainfed treatments of the irrigation experiment conducted at Camilla, GA in 2004 (Guerra et al., 2005).

Georgia primed acclimation study:

Cultivar coefficients for FiberMax© 1944 GLB2 were fit using data from this study as well as the high-biomass rye cover crop study and the predawn leaf water potential study. Simulated and observed mainstem node numbers for 2014 are shown in Figure 30 for selected treatments, and for 2015 in Figure 31. Simulated and observed canopy heights for these treatments are shown in Figure 32 and Figure 33 for 2014 and 2015, respectively. Only the rainfed treatment had a significantly lower yield than the other treatments in 2014 (Figure 34). In 2015, a wet year, the rainfed treatment had a significantly higher yield than the other treatments. The simulations picked up this difference among treatments in 2014, but the simulated yield in 2015 for the rainfed treatment was 362 kg ha^{-1} lower than that for the other treatments.

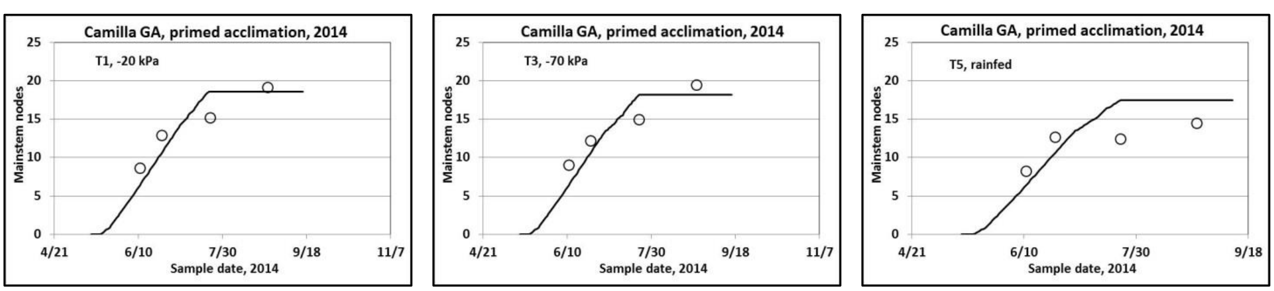


Figure 30. Comparison of simulated and observed number of mainstem nodes for the -20 kPa, -70 kPa, and rainfed treatments for the primed acclimation irrigation experiment conducted at Camilla, GA in 2014 (Meeks, 2017; Meeks et al., 2017).

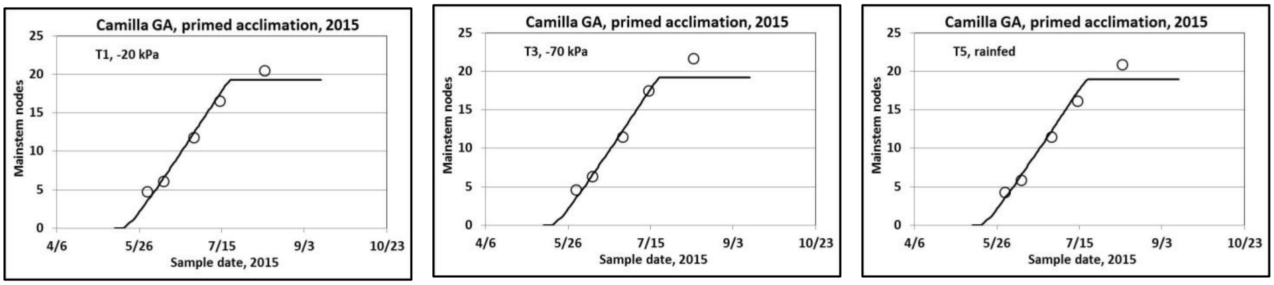


Figure 31. Comparison of simulated and observed number of mainstem nodes for the -20 kPa, -70 kPa, and rainfed treatments for the primed acclimation irrigation experiment conducted at Camilla, GA in 2015 (Meeks, 2017; Meeks et al., 2017).

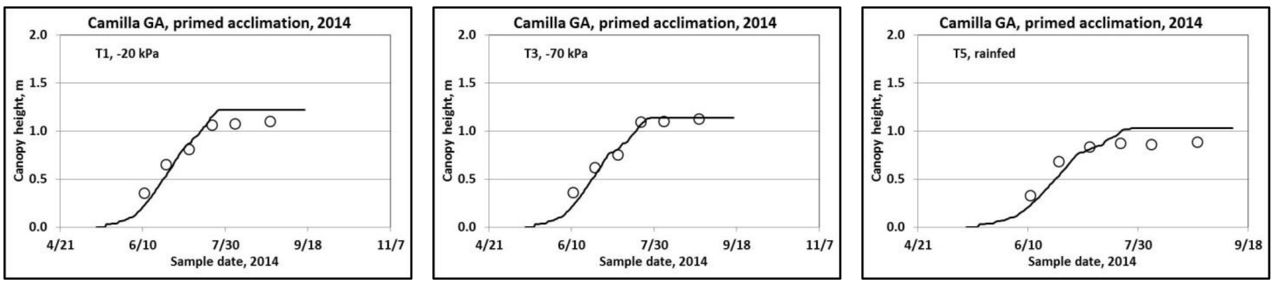


Figure 32. Comparison of simulated and observed canopy height for the -20 kPa, -70 kPa, and rainfed treatments for the primed acclimation irrigation experiment conducted at Camilla, GA in 2014 (Meeks, 2017; Meeks et al., 2017).

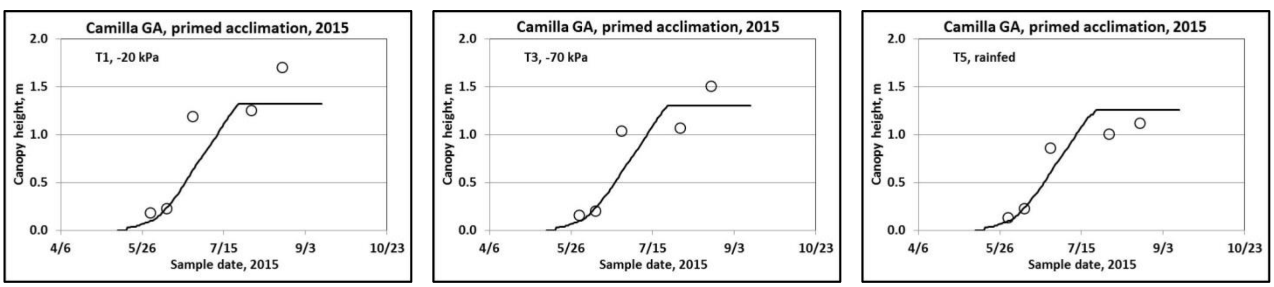


Figure 33. Comparison of simulated and observed canopy height for the -20 kPa, -70 kPa, and rainfed treatments for the primed acclimation irrigation experiment conducted at Camilla, GA in 2015 (Meeks, 2017; Meeks et al., 2017).

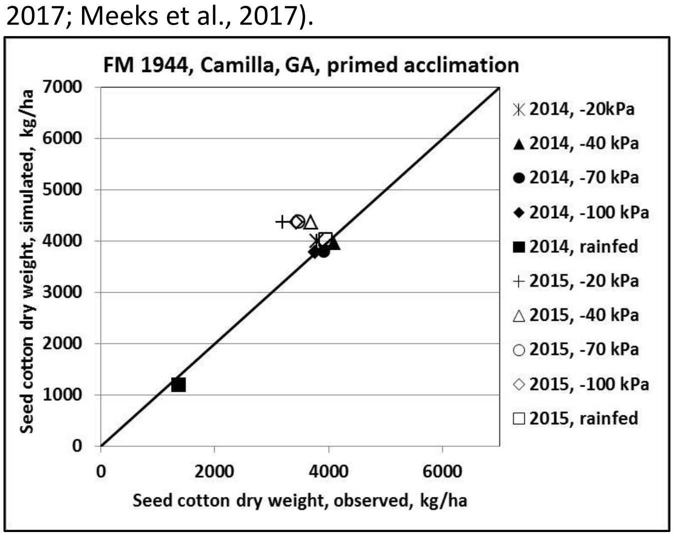


Figure 34. Comparison of simulated and observed seed cotton yield for the primed acclimation irrigation experiment conducted at Camilla, GA in 2014 and 2015 (Meeks, 2017; Meeks et al., 2017).

Georgia high-biomass rye cover crop study:

Simulated and observed mainstem node numbers and canopy height measurements did not match too well in either 2014 or 2015 for this study, using cultivar coefficients that worked well for the two studies in Camilla, GA. In 2014, both simulated mainstem node numbers (Figure 35) and canopy height (Figure 36) increased at too fast a rate after the first sample date. In 2015, the simulated rate of increase in both nodes (Figure 37) and height (Figure 38) were consistent with observed, but the crop appeared to have emerged later than predicted, or grown at a slower rate prior to the first sample date. In 2014, simulated yields matched observed yields well, but in 2015 they were low (Figure 39).

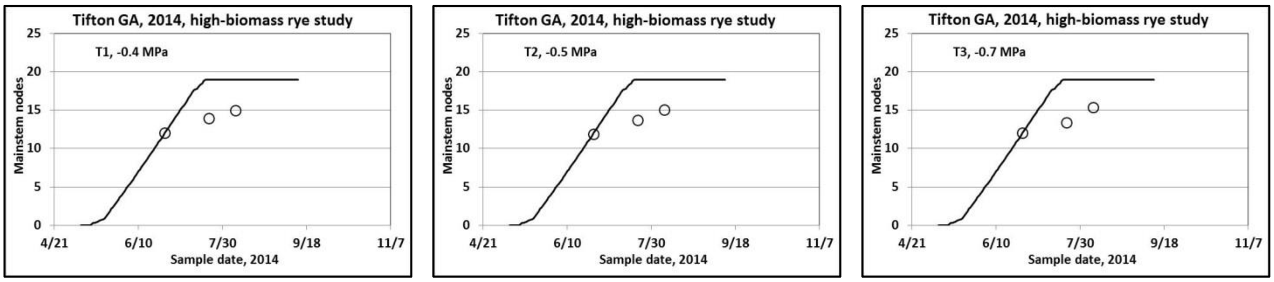


Figure 35. Comparison of simulated and observed mainstem node numbers for the high-biomass rye cover crop experiment conducted at Tifton, GA in 2014 (Meeks, 2017; Meeks et al., 2018).

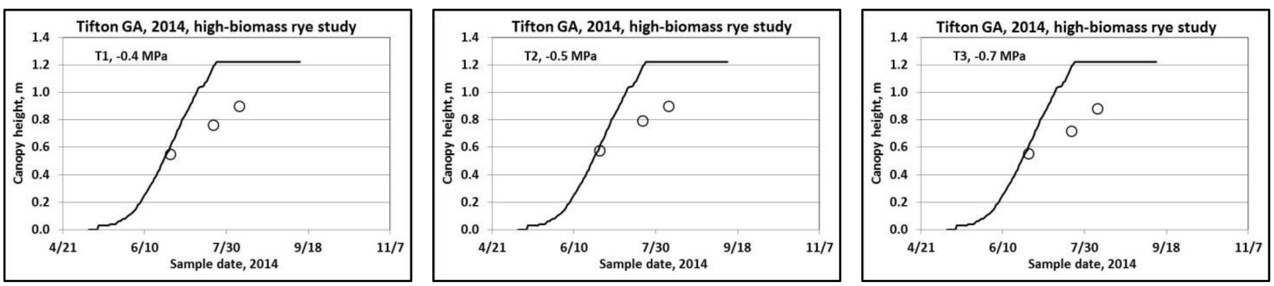


Figure 36. Comparison of simulated and observed canopy height for the high-biomass rye cover crop experiment conducted at Tifton, GA in 2014 (Meeks, 2017; Meeks et al., 2018).

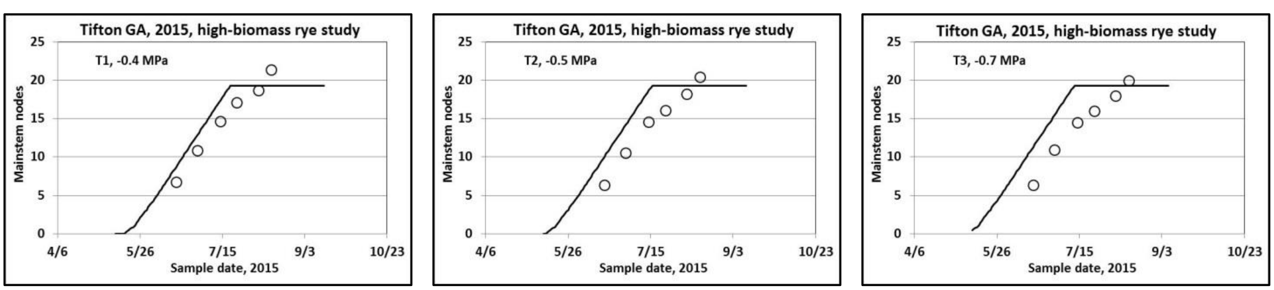


Figure 37. Comparison of simulated and observed mainstem node numbers for the high-biomass rye cover crop experiment conducted at Tifton, GA in 2015 (Meeks, 2017; Meeks et al., 2018).

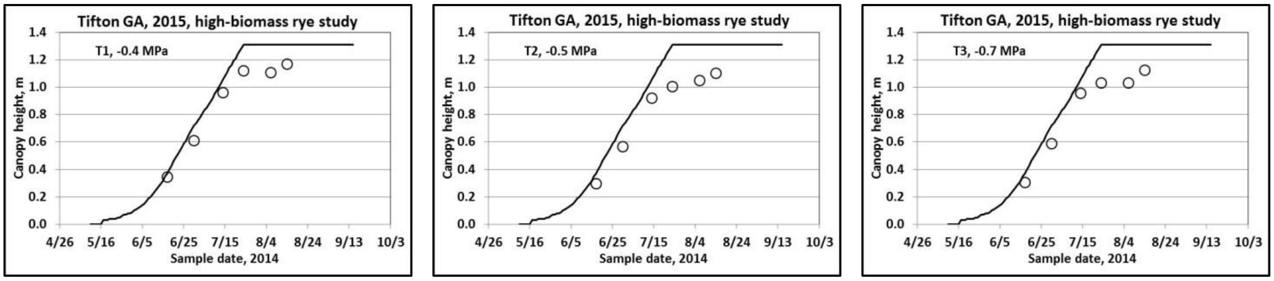


Figure 38. Comparison of simulated and observed canopy height for the high-biomass rye cover crop experiment conducted at Tifton, GA in 2015 (Meeks, 2017; Meeks et al., 2018).

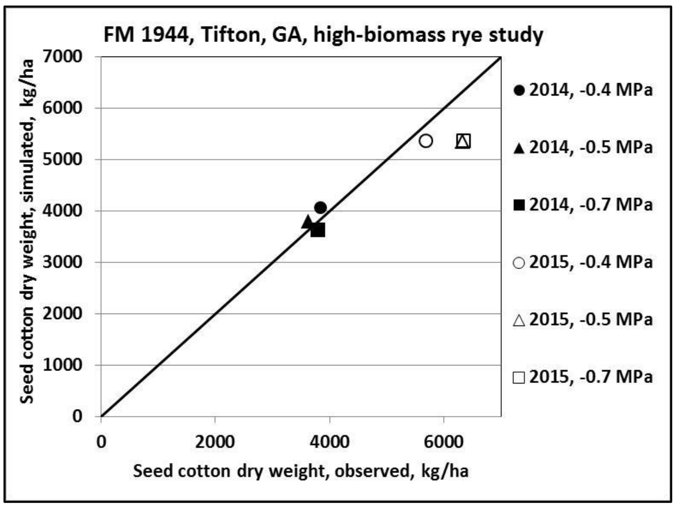


Figure 39. Comparison of simulated and observed seed cotton yields for the high-biomass rye cover crop experiment conducted at Tifton, GA in 2014 and 2015 (Meeks, 2017; Meeks et al., 2018).

Georgia predawn leaf water potential irrigation study:

Mainstem node numbers and canopy height were well-simulated for FiberMax© 1944 GLB2 (Figures 40 and 41), as was yield (Figure 42). We were unable to get simulated yields for Phytogen 499WRF to match observed yields, if cultivar and ecotype coefficients were used that had been set using data from the North Carolina study, and soil profile parameters were set using data for FiberMax© 1944 GLB2. This is an unresolved issue.

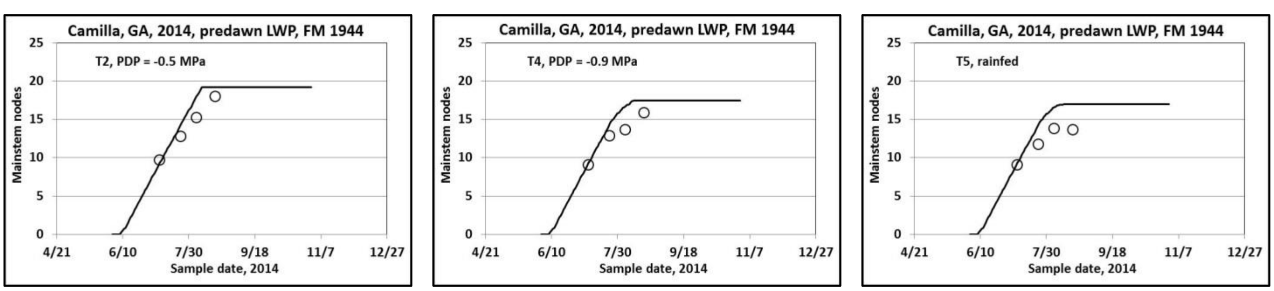


Figure 40. Comparison of simulated and observed number of mainstem nodes for the -0.5 MPa, -0.9 MPa, and rainfed treatments for the predawn leaf water potential irrigation experiment conducted at Camilla, GA in 2014 (Chastain et al., 2016).

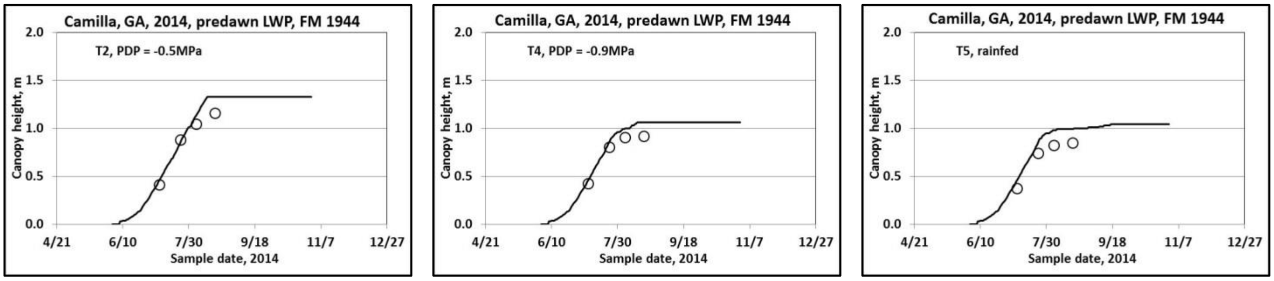


Figure 41. Comparison of simulated and observed number of canopy heights for the -0.5 MPa, -0.9 MPa, and rainfed treatments for the predawn leaf water potential irrigation experiment conducted at Camilla, GA in 2014 (Chastain et al., 2016).

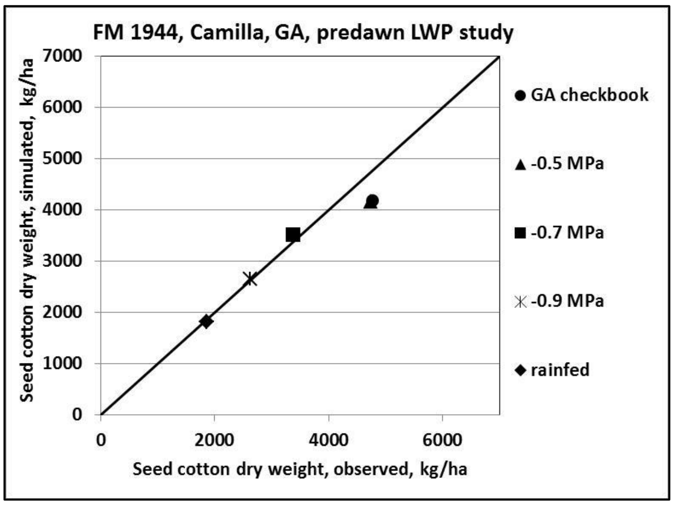


Figure 42. Comparison of simulated and observed seed cotton yield for the predawn leaf water potential irrigation experiment conducted at Camilla, GA in 2014 (Chastain et al., 2016).

North Carolina planting date and irrigation study:

Soil profile and cultivar coefficients were adjusted after species temperature functions were changed based on AZ and TX data sets. These changes were mostly made using 2015 data. However, those affecting canopy height and mainstem nodes were modified to fit 2016 and Ga LWP data for PHY499WRF better. Simulated growth seems to be too slow early in the season for the late planting date in both years, for both cultivars. This may be due to temperature functions still not being correct in the species file. We couldn't find a set of temperature function parameters that worked perfectly for all locations and years. Results for PHY333WRF and PHY499WRF were very similar in both years, for all three planting dates. Therefore, only results for PHY333WRF are shown here.

Observed and simulated boll, leaf, and canopy dry weights for 2015 rainfed and irrigated PHY333WRF are shown in Figures 43-45 for the 6 May, 21 May, and 8 June planting dates, respectively. In general, simulated leaf, boll, and canopy weights fell within the 95% confidence intervals of measured weights for the first two planting dates and both irrigation strategies. However, simulated leaf and canopy weights were low on the last two sampling dates for rainfed treatments planted on 8 June.

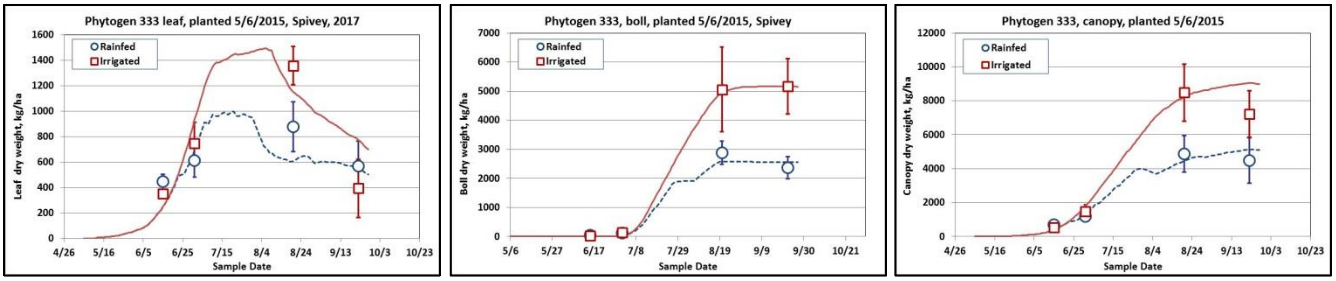


Figure 43. Comparison of simulated and observed leaf, boll, and canopy dry weights for irrigated and rainfed Phytogen 333 planted on 6 May 2015 near Lewiston-Woodville. Error bars indicate 95% confidence limits for measured values.

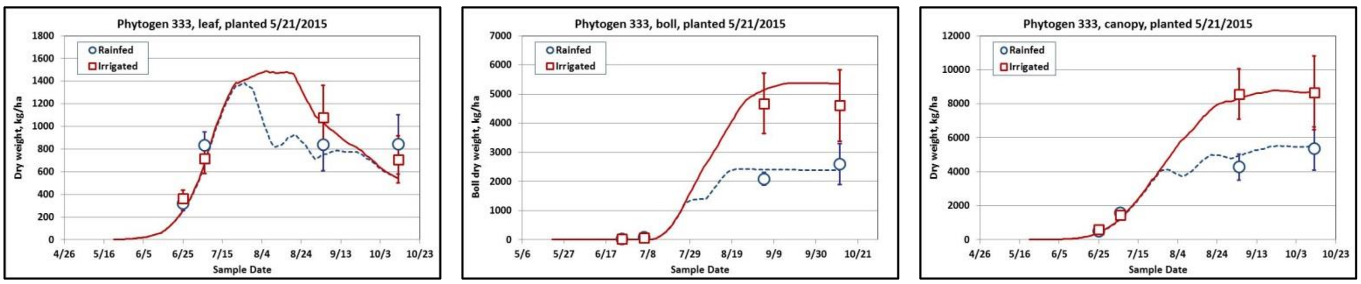


Figure 44. Comparison of simulated and observed leaf, boll, and canopy dry weights for irrigated and rainfed Phytogen 333 planted on 21 May 2015 near Lewiston-Woodville. Error bars indicate 95% confidence limits for measured values.

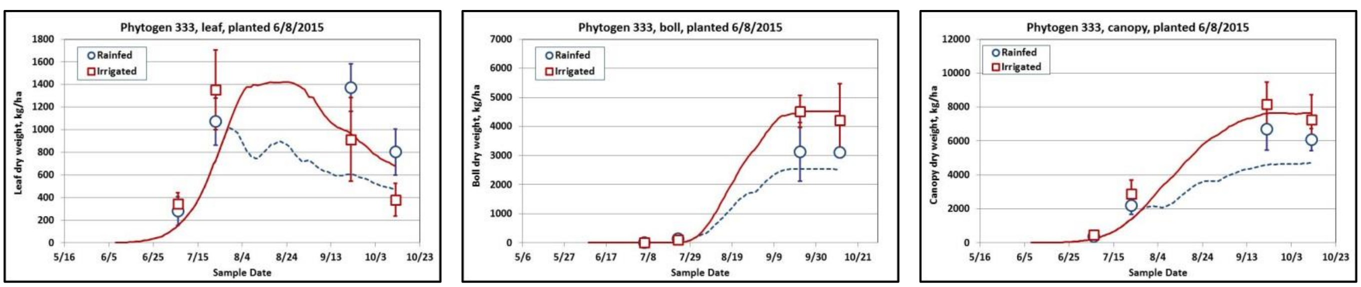


Figure 45. Comparison of simulated and observed leaf, boll, and canopy dry weights for irrigated and rainfed Phytogen 333 planted on 8 June 2015 near Lewiston-Woodville. Error bars indicate 95% confidence limits for measured values.

Simulated values for the 2016 validation data set matched measured PHY 333WRF rainfed boll, leaf, and canopy weights well for all three planting dates (Figures 46-48). However, under irrigated conditions, the model overestimated boll weight on the last two sampling dates for all planting dates. The overestimation may be due to excessive rainfall and wind events in September and October that may have decreased observed weights. Rainfall equaled 1143 mm during the 2016 growing season, compared to 635 mm in 2015. However, 711 mm of this was received in September and October, due to two hurricanes and a tropical storm. The test site received 156 mm of precipitation between 1 and 3 September, 246 mm between 19 and 22 September, and almost 40 mm between 28 September and 1 October, 2016. The test site received another 269 mm from the remnants of Hurricane Matthew between 7 and 9 October. Treatments planted on the first two dates had significant portions of lint on the ground due to these events. Because of the wind moving this lint around, it was not possible to quantify how much lint was actually lost from each plot. Leaf weights were low on the first three sample dates for the last two planting dates—perhaps because of changes made to the temperature functions.

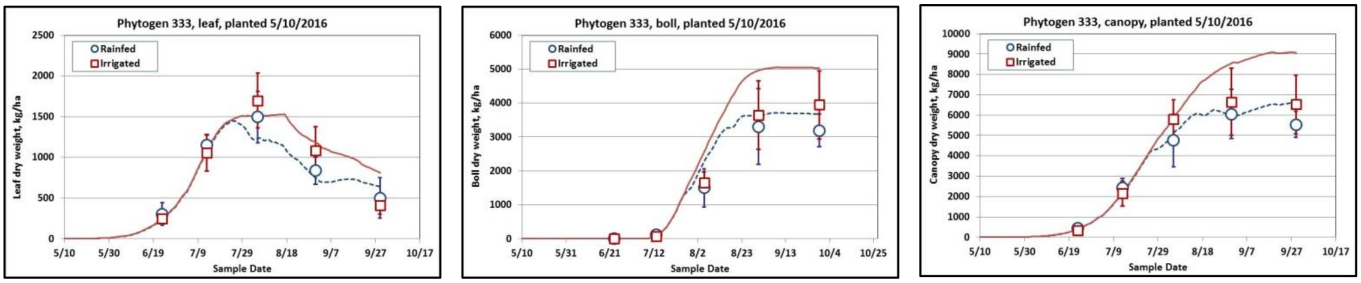


Figure 46. Comparison of simulated and observed leaf, boll, and canopy dry weights for irrigated and rainfed Phytogen 333 planted on 10 May 2016 near Lewiston-Woodville. Error bars indicate 95% confidence limits for measured values.

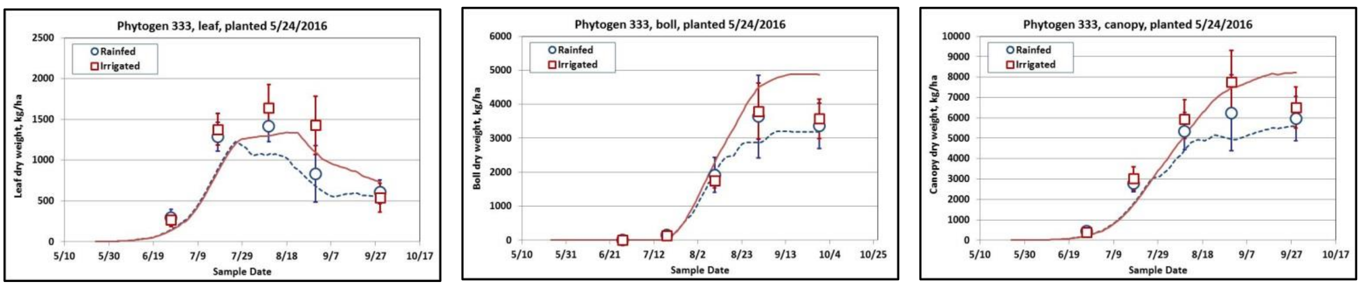


Figure 47. Comparison of simulated and observed leaf, boll, and canopy dry weights for irrigated and rainfed Phytogen 333 planted on 24 May 2016 near Lewiston-Woodville. Error bars indicate 95% confidence limits for measured values.

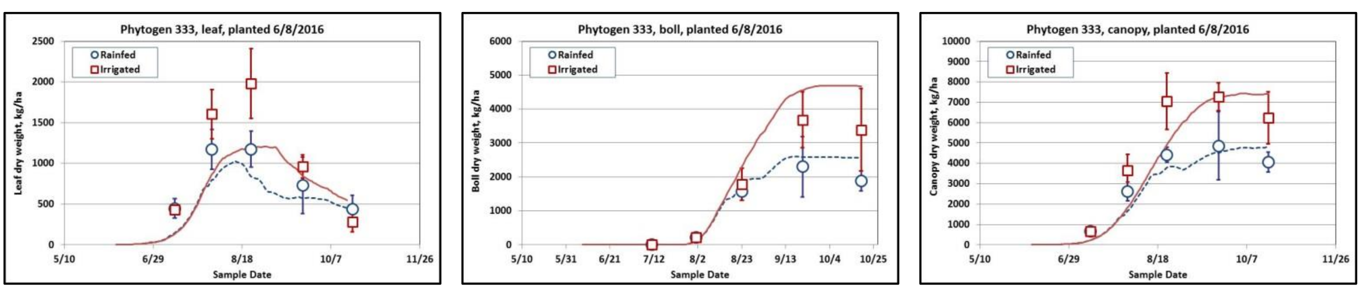


Figure 48. Comparison of simulated and observed leaf, boll, and canopy dry weights for irrigated and rainfed Phytogen 333 planted on 8 June 2016 near Lewiston-Woodville. Error bars indicate 95% confidence limits for measured values.

Conclusions

Twenty-three site-years of field data from 12 cotton experiments performed in Arizona, Texas, North Carolina, and Georgia have been collated. Weather, experiment, soil, cultivar, ecotype, time series, and summary data files in DSSAT format have been created for each experiment. These data files contain information about 202 treatments across a wide range of production environments, from the humid Southeast to the arid Southwest. Information available varies by experiment, but includes leaf area, plant biomass, canopy height and width, mainstem node numbers, yield, root length volume, and soil moisture measurements at multiple depths. These data sets have been used to modify CSM-CROPGRO-Cotton species parameters and several model temperature functions. This has improved model performance across a broad range of environmental conditions and production practices. The data sets will be made available to the DSSAT community of crop modelers. These data sets will be an exceptional resource for continuing improvement of cotton crop growth models.

Some questions/conclusions derived from the simulations:

- Planting into dry seedbed—should not emerge until adequate soil moisture (irrigation). The model allows plants to germinate and emerge even when soil water is below the wilting point. Emergence is only a function of temperature currently.
- Twin rows are not an option in the model, so it did not respond well to increased plant density achieved through use of twin rows.
- Simulated root growth should be affected by soil chemical and physical properties. Increases in rooting depth, in particular, should be influenced by these properties.
- Questions remain about the effect of stress and environmental conditions on partitioning and phenological development. The timing of cessation of canopy height and leaf area increase, and the beginning of boll development seems to vary among treatments and years, and in some cases we were unable to determine soil and cultivar parameters that worked well for all treatments for the same cultivar. Nitrogen and drought stress should probably affect canopy height more negatively than they do at present.
- N stress is too great using the Ritchie-Ceres soil evaporation method in some cases. Suleiman-Ritchie method for estimating soil evaporation has problems too: it allows bare soil evaporation to draw water from 200 cm down, even if water is below the wilting point in some layers.
- No warning is given if initial soil water is below the wilting point in one or more layers. Roots do not grow into a layer that is below the wilting point. This is as it should be, but it took several hours to determine why roots were not increasing as expected in the Texas irrigation timing experiment (Bordovsky et al., 2015; Adhikari et al., 2016). This also raised the question as to just how dry do the lower layers of the soil get in AZ and TX?
- There was a lot of confusion among researchers as to how yields were reported, and how to compare them to the dry seed cotton weights that are output as “grain” weight by the model. Lint, seed yield components would be good additions to the simulated results, but would require code modifications.
- Should R1 be defined as pinhead square rather than first open flower? R1 should denote the beginning of reproductive growth. Perhaps other stages also need to be redefined for the cotton model.
- Having data from multiple years per location and varying production environments is both necessary and challenging when making modifications to improve model performance.

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