Crop Modeling Activities at South Asia AgMIP Workshop

ICRISAT, Andra Pradesh, India
February 20-24, 2012

Goals of the Crop Modelers during this Workshop: 1) to calibrate and intercompare multiple crop models (APSIM, DSSAT, INFOCROP, and STICS) against rice and wheat data at sites in South Asia, 2) to simulate growth and yield sensitivity of those four crop models for rice and wheat to temperature and carbon dioxide levels, and 3) to demonstrate the process of predicting district-level yield of peanut for three crop models (APSIM, DSSAT, and INFOCROP), following steps of calibrating, aggregating simulated outcome over multiple soils, sowing dates and weather sites, and finally predicting historical yields for Anantapur district after accounting for bias of observed district yields versus simulated. Data on growth, soils, management, and weather used during the Workshop were provided by the following colleagues:

1. Peanut – Piara Singh and Nageswara Rao, ICRISAT center, India
2. Rice – Perry Poulton, CSIRO, Australia (original data collector not known)
3. Wheat – Naresh Kumar, ICAR, India (original data collector not known)

The following persons participated in crop modeling activities on four crop modeling teams: **DSSAT** (Ken Boote, Gerrit Hoogenboom, U. Singh, P. Singh, K. Srinivas, Raji Reddy, V.S. Bhatia, Geethalakshimi V., Dilwar A. Choudury, and A.V.M. SubbaRao), **APSIM** (John Hargreaves, Perry Poulton, Nageswara Rao V., M. Shamin, Kripan Ghosh, Anup Das, N. Subash, Tariqul Islam), STICS (Jean-Louis Durand, Dominic Ripoche, and Giacomo De Sanctis), and **INFOCROP** (Naresh Kumar, V. S. Bhatia, A.V.M. SubbaRao). A brief discussion on Monday afternoon confirmed the crop modeling teams and the modeling activities to concentrate on. Data and associated weather for peanut in Anantapur and wheat near New Delhi were provided prior to the Workshop to APSIM and DSSAT modelers, and to all participants at the meeting via CD-ROM.

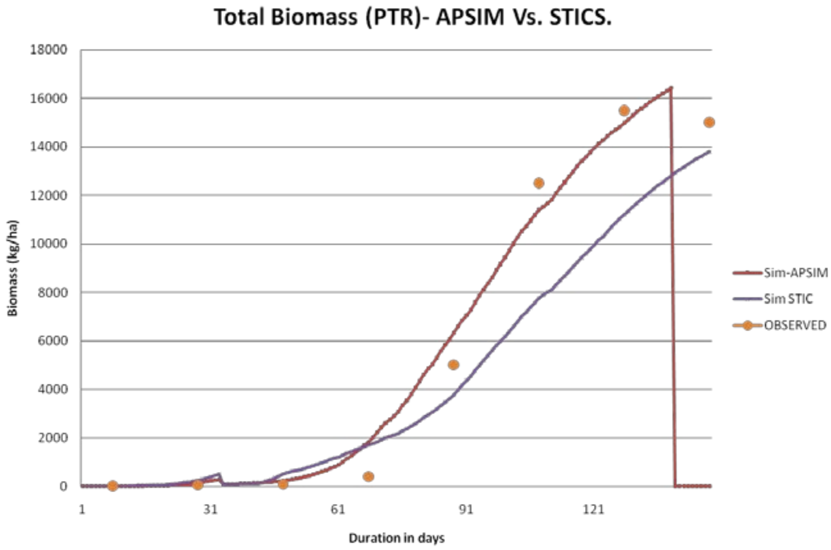
SUMMARY OF CROP MODELING ACTIVITIES:

1. Calibrated four crop models (APSIM, DSSAT, INFOCROP, and STICS) to simulate rice growth and yield at Ludiana, Punjab.
2. Calibrated four crop models (APSIM, DSSAT, INFOCROP, and STICS) to simulate wheat growth and yield with data collected near Delhi, India.
3. Evaluated rice yield response to temperature (-2, 0, +2, +4, +6C vs. baseline) over three carbon dioxide levels (360, 540, and 720 ppm) with four crop models. Discovered that the rice models differed in response to temperature, and that yield response to CO_2 was less under limiting N supply.
4. Evaluated wheat yield response to temperature (-2, 0, +2, +4, +6C vs. baseline) over three carbon dioxide levels (360, 540, and 720 ppm) with four crop models. Discovered that the wheat models differed in response to temperature, and that yield response to CO_2 was less under limiting N supply.
5. Calibrated APSIM, DSSAT, and INFOCROP models versus peanut experimental data (TMV-2 cultivar in 36 treatments over 6 seasons) for Anantapur, India.
6. Developed methodology to predict district-level peanut pod yield for the Anantapur, with the three peanut crop models, that included calibrating to experimental yields, predicting district yield by aggregating over 9 weather sites, 3 sowing dates, and 3 soils, and lastly, doing a bias-adjustment on that simulated district yield to re-scale to observed district-level yields. The process worked well for water-limited Anantapur district. The aggregation process needs to consider many factors such as weather, sowing date, soils, and amount of background irrigated production.

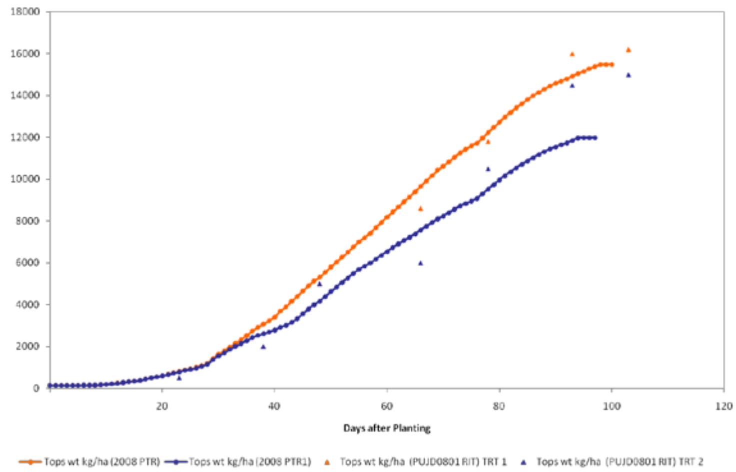
Outcomes of the Crop Modeling Activities:

Calibration of Four Crop Models for Rice:

The rice experiment was conducted in 2008 at Ludhiana, Punjab (investigators not known). There were four treatments: full flood, and aerobic rice irrigated at 20, 40, or 70 kPa soil water potential. The crop modelers calibrated their models to all four treatments. Results are shown for total biomass over time and grain yield, or for final biomass and grain yield.



Figures 1 illustrates predicted total crop biomass over time for APSIM-ORYZA and STICS rice models after calibration to the treatments. The simulated total crop biomass for STICS was lower compared to APSIM. Causes were not discovered. Figure 2 illustrates the prediction of total crop mass for the CERES-Rice model for several of the treatments. Figure 3 illustrates the prediction by APSIM-ORZYA of time-course of grain yield over time for the four different treatments. For INFOCROP, the results are shown for final crop mass and final grain yield for the four treatments (Figure 4).



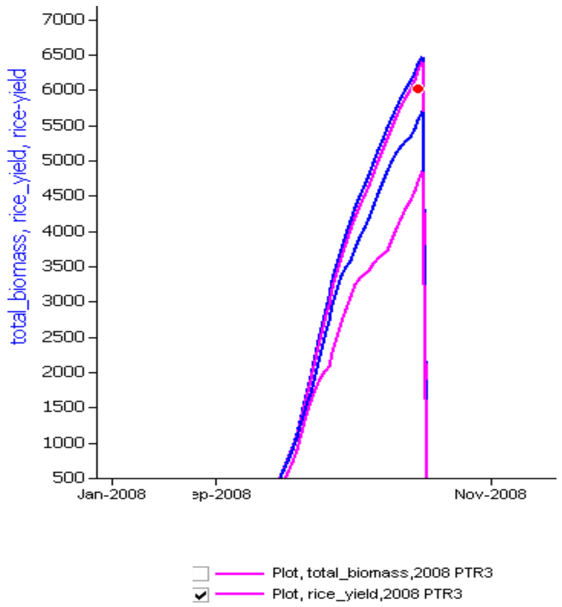
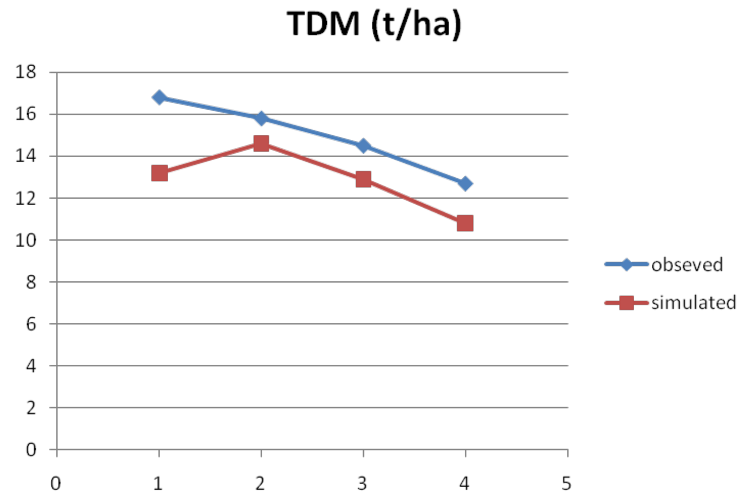


Figure 1. Time course of total crop mass predicted for rice grown in 2008 at Ludhiana, Punjab as simulated by APSIM-ORYZA and STICS models, after calibration.

Figure 2. Time course of total crop mass predicted for rice grown in 2008 at Ludhiana, Punjab as simulated by CERES-Rice model, after calibration.

Figure 3. Rice grain yield predicted at Ludiana, Punjab in 2008, as simulated by APSIM-ORYZA, after calibration.

There were some issues learned about the data. First, only one of the treatments was true flooded paddy, and the other treatments were water-limited. That required consideration for soil water balance limitation and rooting depth with the different models. In addition, the soil organic C and initial mineral N was deemed to be a problem (by the APSIM modelers who increased SOC from 0.5 to 0.85% and increased initial ammonium level). We will later see that N limitation caused a problem in the simulation of yield response to CO_2, where the yield response to CO_2 was limited by N supply. The N fertilization was only 120 kg N ha^{-1}.



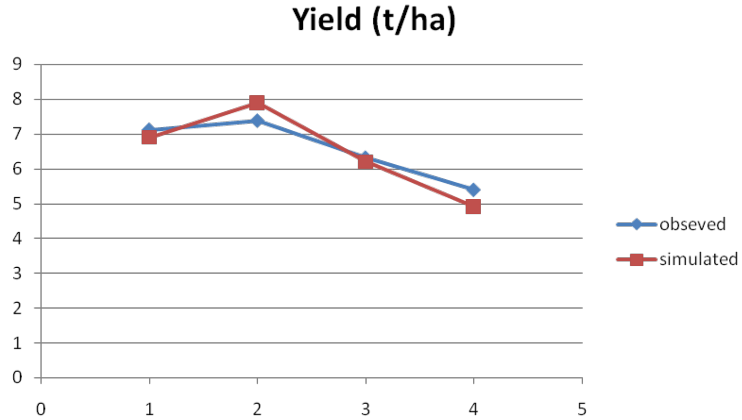


Figure 4a and 4b. Final crop mass and grain yield of 4 rice treatments, observed compared to that simulated by INFOCROP after calibration. The x-axis has no meaning and reflects four treatments.

Rice Model Sensitivity to Temperature and CO_2:

The calibrated rice crop models were simulated for five temperatures (-2, 0, +2, +4, +6C compared to the baseline 30 years of data provided by Alex Ruane) across three carbon dioxide levels (360, 540, and 720 ppm) in factorial combinations. While Alex provided the weather files, the modelers except for INFOCROP found it more convenient to use the environmental modifications sections of their model input parameters. The climate sensitivity simulations were conducted for the flooded paddy treatment with the fixed N application amount (120 kg N ha^{-1}) and schedule of applications. INFOCROP was not compared at this step because of difficulties in creating weather files.

The rice crop models generally predicted lower yield as temperature increased from baseline to higher temperature (at ambient 360 ppm), but the models differed in their response. DSSAT was slightly more responsive to elevated temperature than APSIM-ORYZA. STICS was highly sensitive to temperature, having zero yield at +6C and also lower yield at -2C than ambient.

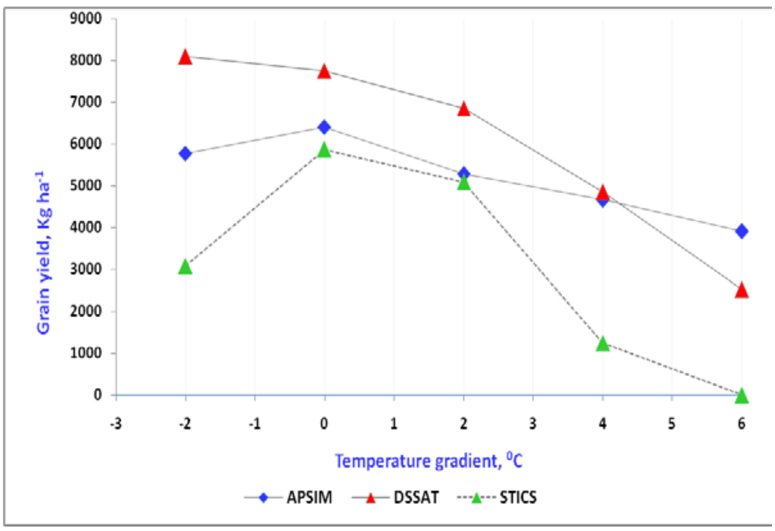


Figure 5. Sensitivity of predicted rice yield to temperature change at 360 ppm for APSIM, DSSAT, and STICS models

The same models were also evaluated for sensitivity to temperature at 720 ppm CO_2. The relative response to temperature appears to be mostly the same at elevated CO_2.

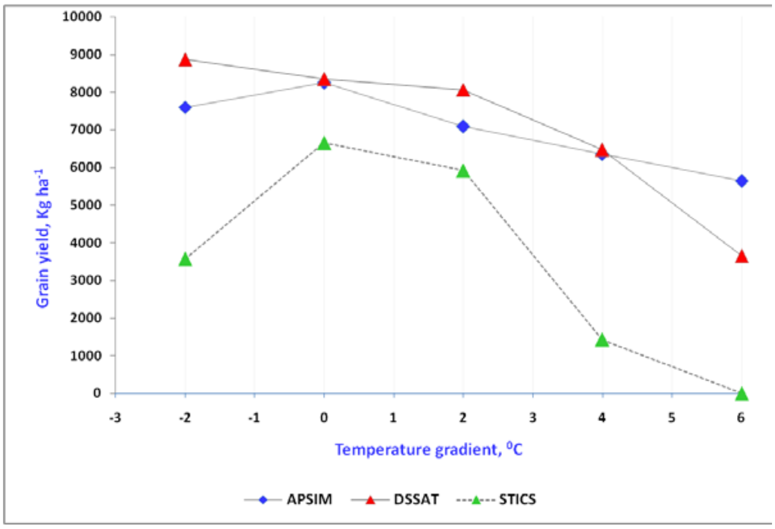


Figure 6. Sensitivity of predicted rice yield to temperature change at 720 ppm for APSIM, DSSAT, and STICS models

The sensitivity to CO_2 is shown in Table 1 below for the rice crop models, as a percentage of yield response compared to the baseline. The responses to CO_2 differed for the crop models, but there is an explanation. APSIM modelers had bumped up the soil organic carbon from 0.50 to 0.85% and increased initial ammonium. As a result, APSIM-ORYZA model predicted response is about what we would expect (about 30% response to doubling, 360 to 720 ppm, is expected under conditions of no water or N stress). By contrast, the DSSAT and STICS model input files were not modified for SOC or initial mineral N, and it appears that the 120 kg N ha^{-1} rate was limiting the response to CO_2, more so under high yield conditions, and almost not at all under conditions where temperature limited yield. Lower modeled responses to CO_2 under N-limitation are confirmed by field data for lower response to CO_2 under N-limiting conditions for rice and wheat.

Base CO_2 (360 ppm)	% change in grain yield over base line					
	APSIM		DSSAT		STICS	
Temperature, °C	540 ppm	720 ppm	540 ppm	720 ppm	540 ppm	720 ppm
-2	22	31	4	10	8	16
0	20	29	4	8	7	13
2	22	34	12	18	9	16
4	24	36	19	34	8	14
6	29	44	23	45	--	---

Calibration of Four Crop Models for Wheat:

The wheat experiment was conducted near Delhi. There was one treatment with N applications and irrigation information provided. However, irrigation was deficit, causing some soil water limitation. Results are shown for total biomass over time and grain yield, or for final biomass and grain yield.

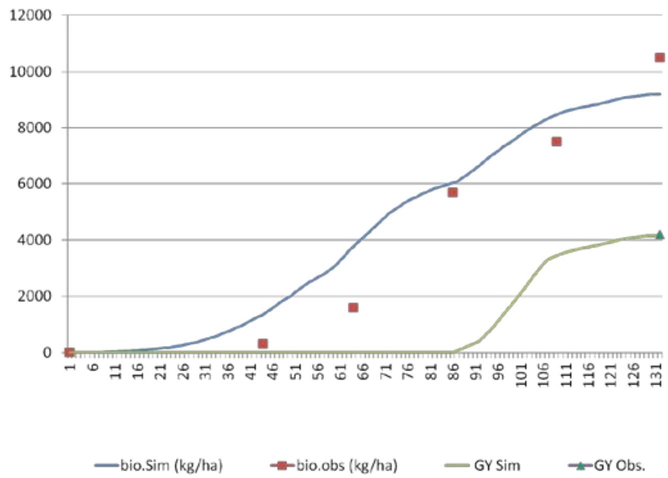


Figure 7. Time course of total crop mass and grain yield predicted for wheat by APSIM-wheat model after calibration.

The STICS predictions of total dry matter, grain yield, and leaf area index are shown in Figure 8. Predictions are generally satisfactory, except for slight over-prediction of biomass. The INFOCROP model simulations in Figure 9 also illustrate over-prediction of total biomass, despite good prediction of final grain yield.

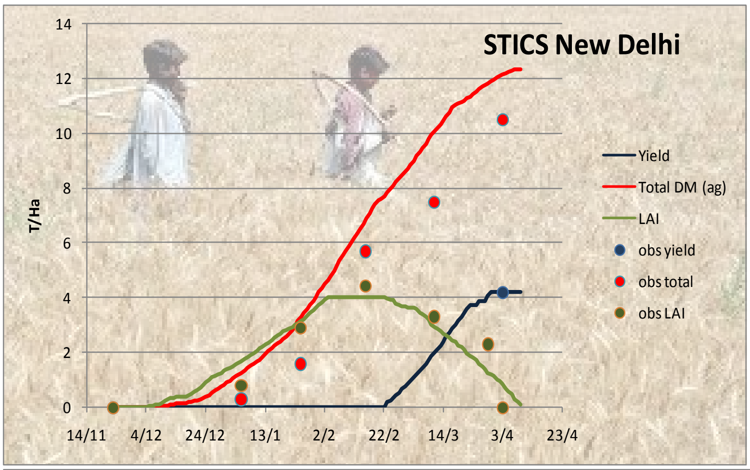


Figure 8. Time course of total crop mass LAI, and grain yield predicted for wheat by STICS-wheat model after calibration.

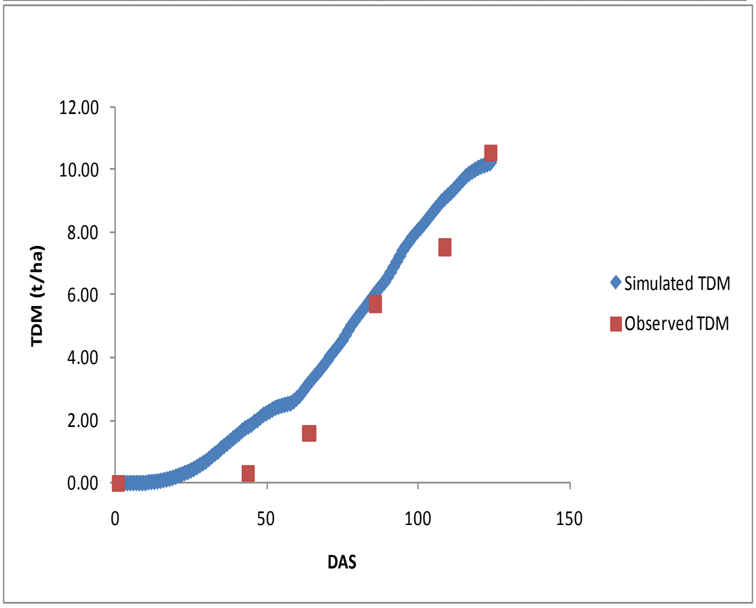
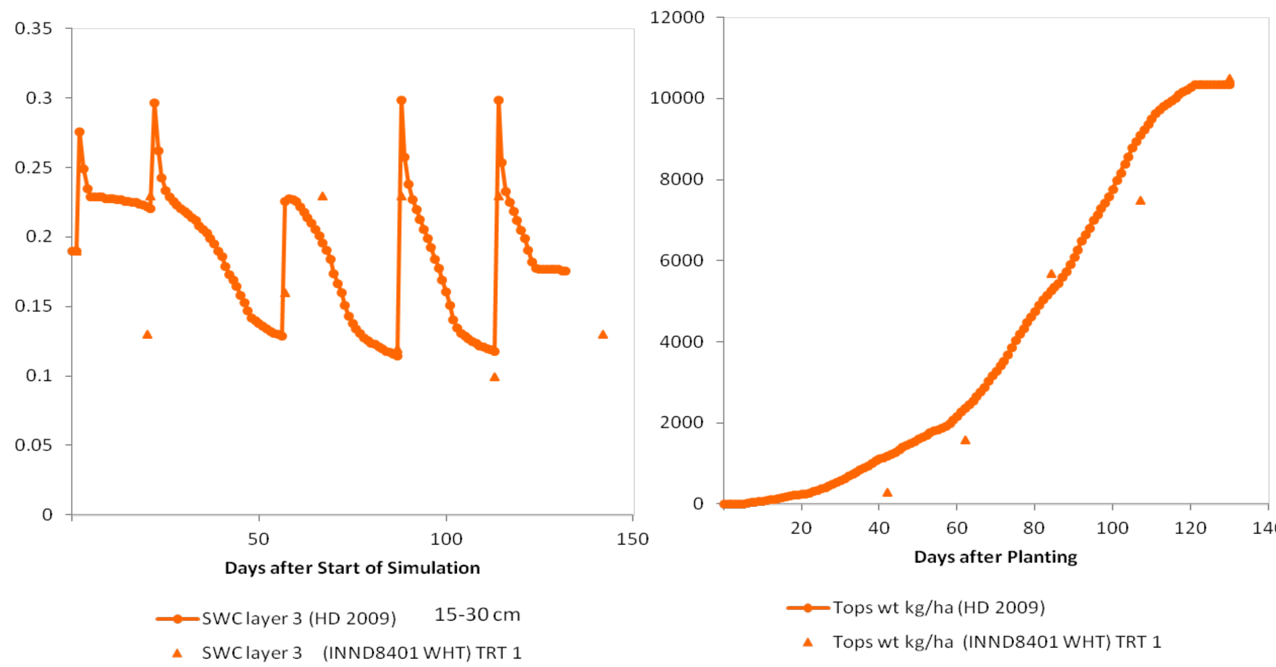


Figure 9. Time course of total crop mass predicted for wheat by INFOCROP-wheat model after calibration.

DSSAT-CERES-wheat model predictions of total crop mass in Figure 10b also show slight over-prediction of biomass in early season. The common nature of all models to over-predict early season biomass, may say as much about poor data during early season as it does about the crop models. Simulated soil water content in Figure 10a predicts well and confirms that soil water was limiting.

Figure 10a and b. Time course of soil water and total crop mass predicted for wheat by DSSAT-CERES wheat model.



Wheat Model Sensitivity to Temperature and CO_2:

The calibrated wheat crop models were simulated for five temperatures (-2, 0, +2, +4, +6C compared to the baseline 30 years of data provided by Alex Ruane) across three carbon dioxide levels (360, 540, and 720 ppm) in factorial combinations. While Alex provided the weather files, the modelers found it more convenient to use the environmental modifications sections of their model input parameters. The climate sensitivity simulations were conducted using the fixed schedule of irrigations and N applications and that aspect could represent limitations of water or N under altered temperature or CO2 conditions.

The wheat models generally predicted lower yield as temperature increased from baseline to higher temperature (at ambient 360 ppm), but the models differed in their responses. Correctness of the simulated response will need to be tested with published data that compares wheat yield response to temperature obtained from latitude or elevation changes on a given cultivar.

Wheat yield sensitivity to CO_2 is shown in Table 2 below for the rice crop models, as a percentage yield change at 540 or 720 ppm compared to the baseline. The responses to CO_2 differed for the crop models. Similar to the rice situation, the yield response to doubled CO_2 from 360 to 720 should approach 30% (literature metadata average), but three of the four crop models predicted less response than that. We presume that simulated yield at elevated CO_2 was N-limited since the N application was not changed and water was also limiting (some models reduce N uptake under water limitation). It will be important to evaluate the crop model response to CO_2 under non-limiting N and water conditions for this site to confirm the possibility that N limitation is the cause. In addition, most of the crop models output an N-stress indicator which should also be looked at.

Model	540 ppm	720 ppm
INFOCROP	4	6
STICS	6	10
CERES-Wheat	15	29
APSIM-Wheat	11	12

Predicting District-Level Peanut Pod Yields with APSIM, DSSAT, and INFOCROP Models:

Long-term district-level pod yields for peanut were available for the Anantapur District (1962 to 2007). Weather data was also available beginning in 1980. In addition, 6 years of experiments (36 treatments varying in sowing date, sowing density, irrigation, and rainfed) were available for the TMV-2 cultivar for the seasons of 1986, 1987, 1988, 1989, 1990, and 1993 at Anantapur (data courtesy of the University there and ICRISAT, with data provided by Piara Singh, ICRISAT center).

Three crop models (APSIM, DSSAT-CROPGRO-Peanut, INFOCROP) were calibrated to the experimental data with targets first of phenology (anthesis and maturity), then with a focus, in order, on final pod yield, total crop biomass, and to a lesser extent LAI, seed size, and harvest index. The model calibrations are shown in Figures 12, 13, and 14 for APSIM, DSSAT, and INFOCROP, indicating good predictability of pod yield across the 36 treatments. INFOCROP calibration is not yet complete so results are preliminary.

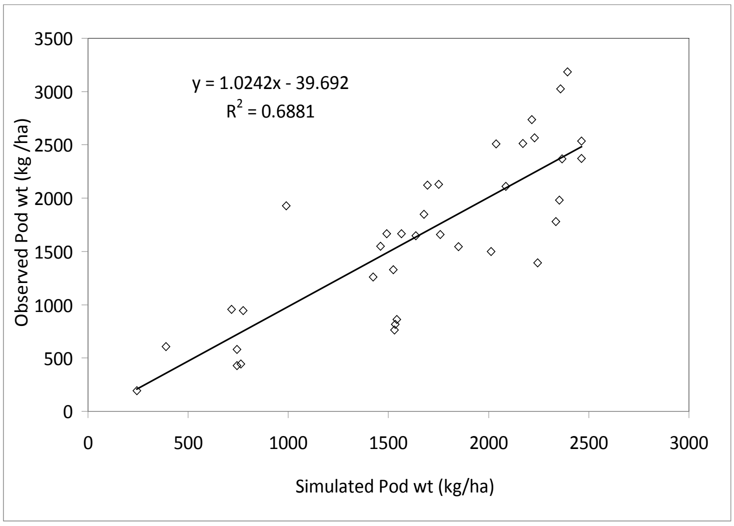


Figure 12. Observed versus simulated pod yield for peanut over 36 treatments at Anantapur with the DSSAT peanut model.

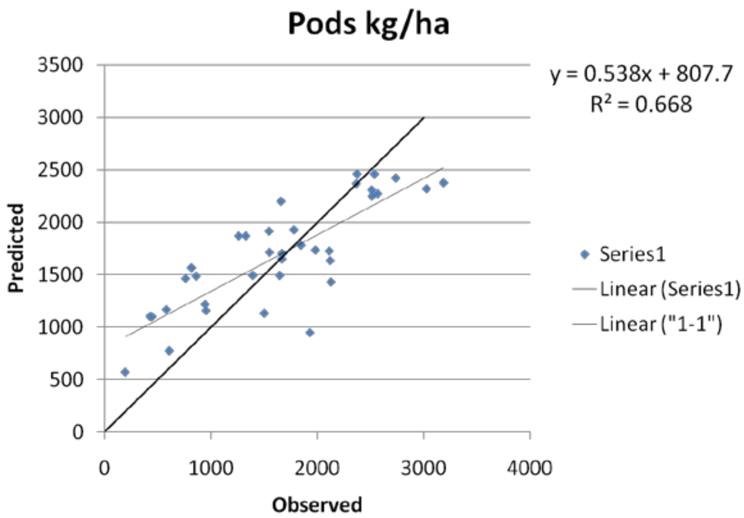


Figure 13. Simulated versus observed pod yield for peanut over 36 treatments at Anantapur with the APSIM peanut model.

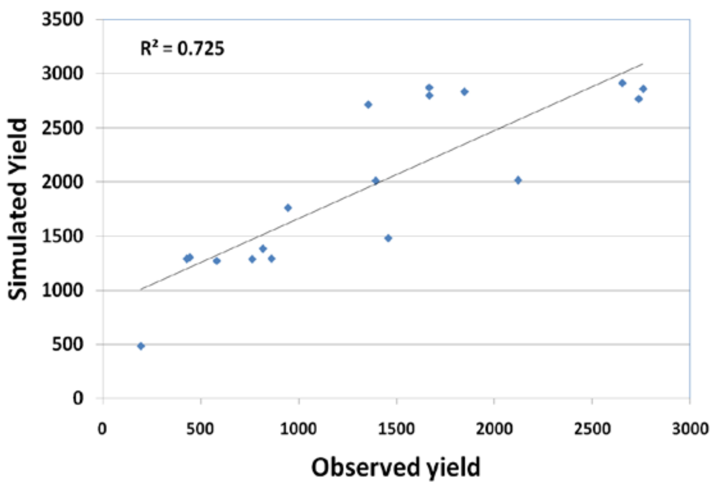


Figure 14. Simulated versus observed pod yield for peanut over 36 treatments at Anantapur with the INFOCROP model.

Aggregation of simulated yields over multiple soils, sowing dates, and weather sites for the district:

Rainfall was available for 8 other sites in the Anantapur region, so 9 total weather sites were prepared, all using same Tmax, Tmin, and Solar Radiation. We simulated three different soils (0.01 volumetric less, standard, and 0.01 volumetric more soil water). The standard soil had been calibrated by Piara Singh for drained upper limit and lower limit, by comparison to measured soil water data. In addition, we simulated three dates of sowing, with windows starting June 16, July 1, and July 16, sowing when sufficient rainfall had occurred to reach 80% of field capacity in the upper 30 cm of soil. Soil was initiated June 1 near the lower limit (water depleted). There were 81 combinations of "treatments" per year. We took the average of those 81 to represent simulated district yield for that year. Then we computed the bias, the slope of the observed district yields (1980 to 2007) versus the simulated district yields as shown in Figure 15. The slope (with no intercept) was used as the bias adjustment to adjust simulated yield down by the factor (0.6952) in the case of the DSSAT model. The same was done for APSIM.

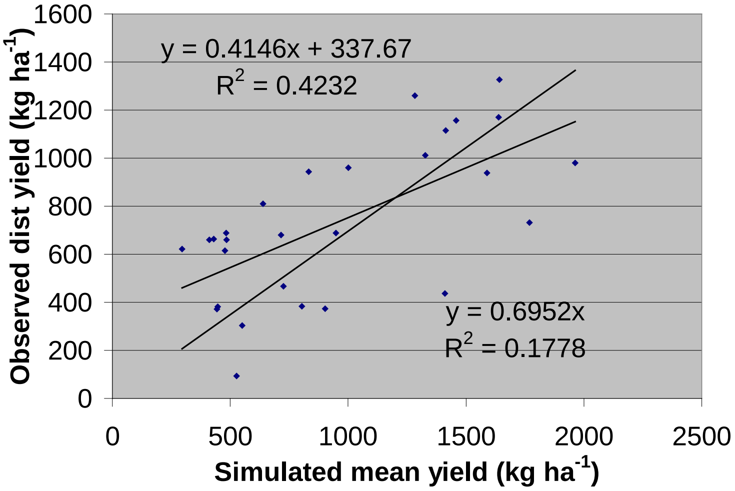


Figure 15. Observed versus simulated pod yield for peanut for Anantapur district with the DSSAT peanut model.

The predicted bias-adjusted district yields over time are shown in Figures 16 and 17 for DSSAT and APSIM, respectively. INFOCROP simulations will be completed at a later time.

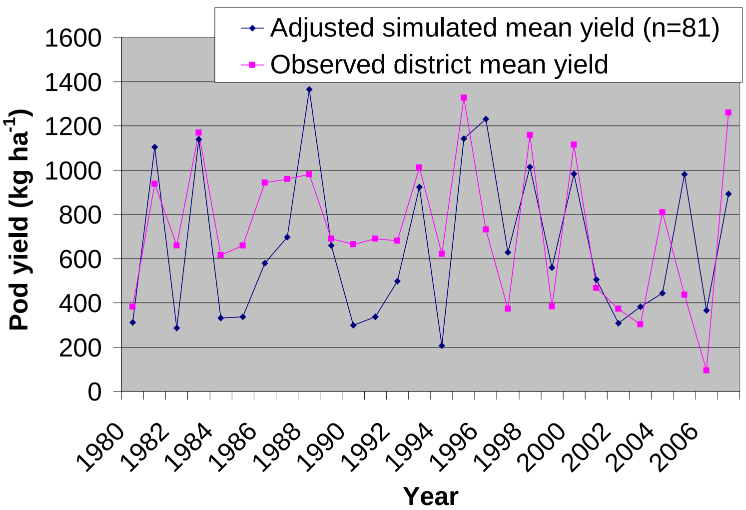


Figure 16. Bias-adjusted simulated pod yield and observed district-level pod yield for Anantapur district simulated with DSSAT peanut model.

The DSSAT model appears pick up a good portion of the yield variation that is primarily associated with low rainfall years. The APSIM model, while being in the middle of the observed because of bias adjustment, appears to not pick up enough of the weather variation. The process is not yet complete, as APSIM modelers will be re-evaluating the soil water limitations in their model to better predict the water-limitations. This was also evident in the calibration to experimental data, indicating that the two models differ in simulating water deficit processes.

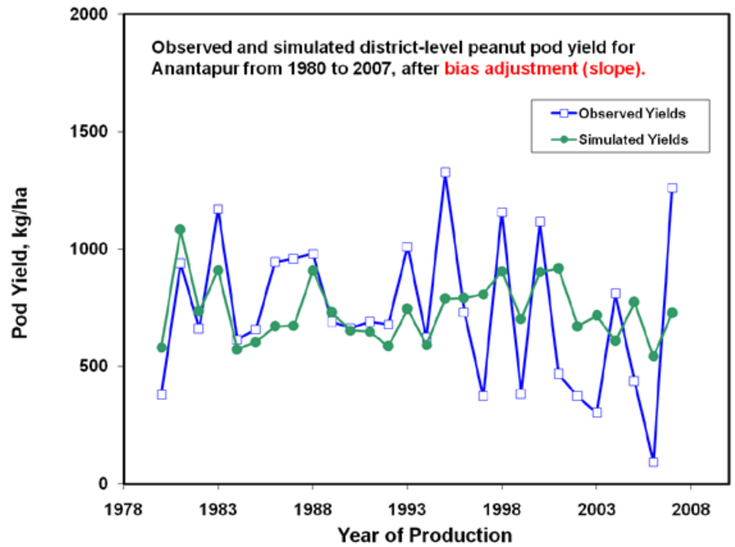


Figure 17. Bias-adjusted simulated pod yield and observed district-level pod yield for APSIM peanut model.

Next steps in predicting district-level peanut yield will involve evaluating methods of weighting the aggregation according to the predominant weather sites, according to predominant soils, and predominant sowing dates. The Indian researchers will find data to document the area distribution to allocate to given weather sites, to given soils, and given soils. They will also try to account for the 10% of area devoted to irrigated production in the post-rainy season that is considered in the district-yield data that influences the interannual yield variability.

Planned publications:

Nageswara Rao and Piara Singh will lead a multi-authored paper. Approaches and Methods for Predicting District-level Peanut Yields in Anantapur District with three crop models

Potential papers mentioned:

Raja Reddy and others – Predicting District-Level Rice and Maize Production in Anantapur District.

A.V.M. SubbaRao, and other – Predicting District-Level Production for Multiple Crops throughout India.

J.W. Jones and many others – Evaluating Climatic Factor Effects on District-Level Yields with Crop Models and Statistical Approaches.