Crop Modeling Activities at AgMIP-South America Workshop

Campinas, Brazil
August 1-5, 2011

Data were requested from Brazilian colleagues prior to the August 1-5 Workshop, for the purpose of serving as sentinel sites from which participants could do crop model intercomparisons, model sensitivity to climatic factors (temperature, CO2, rainfall, and N fertilization), and model response to baseline versus climate scenarios. Data on growth, soils, management, and weather were provided by the following groups:

1. **Maize – Camilo L. T. Andrade, Sete Lagoas,**
2. **Soybean – Jose Renato Bouças Farias, Londrina**
3. **Wheat – Jose Maurico Fernandes**
4. **Rice – Alexandre B. Heinemann**
5. **Sugarcane – Fabio Marin**

Three modeling groups were represented: **DSSAT** (Ken Boote, Camilo Andrade, Santiago Meira, Edgardo Guevara on CERES-Maize; Fabio Marin and Abraham Singels with CANEGRO), **APSIM** (Peter Thorburn, Alex Heinemann, and K.P.C. Rao) and **STICS** (Jean-Louis Durand, Dominique Ripoche, and Patrick Bertuzzi). Decision was quickly made to concentrate on maize because excellent time-series data were available and because all modelers were ready to tackle maize. Data sets on soybean and wheat were somewhat less complete (less or no time-series data) so we did not try to model these two crops. In addition the STICS group wanted to focus on maize first. Preliminary successful simulations of soybean were made with CROPGRO-Soybean and APSIM-Soybean, but full exploration of sensitivity analyses was not explored because of time limitations.

The maize model was successfully calibrated with the APSIM model and the STICS model, and had previously been calibrated for CERES-Maize by Camilo Andrade. Time-series simulations of the three models are not available to present (observed data are proprietary, not published yet); however, the sensitivity to climatic factors was completed and simulations of climate scenarios vs. baseline were conducted. These results will be presented.

The sugarcane crop was simulated by APSIM and CANEGRO models by Fabio Marin, Peter Thorburn, and Abraham Singels. They actually had done much of the work prior to the Workshop, and did conduct sensitivity analyses that will be presented here.

Rainfed rice data was provided by Alex Heinemann who had previously calibrated the APSIM-ORYZA model to this data. During the workshop, he calibrated the CERES-RICE model to this data. During the workshop, Alex completed sensitivity analyses of both rice models to climatic factors and to climate scenarios (the most complete effort of any group and he did it as a one-person show). These results will be presented.

The remainder of this report will focus on simulations of maize first, then sugarcane, and then rice (each crop as a separately discussed activity).

I. Data, Model Adaptation, and Sensitivity Analysis with three Maize Crop Models

A. Data Description – Maize – Camilo Andrade

Plant Data
The trial was carried out at Embrapa Maize and Sorghum experimental station, located in Sete Lagoas, MG, Brazil, (latitude 19° 27' 17 S, longitude 44° 10' 19 W e elevation 731 m). Local climate is classified as Cw according to Köeppen (OMETTO, 1981). The soil is classified as Very Clayey Red Oxisol (PANOSO et al., 2002).

The cultivar BRS 1030, single-cross hybrid developed by Embrapa Maize and Sorghum, was sown 5 cm deep, on February 21, 2009. Final crop stand was 6.67 plants per m^{-2}. Fertilizer use consisted of 32 kg ha^{-1} of N, 112 kg ha^{-1} of P_2O_5 and 64 kg ha^{-1} of K_2O, at planting. Fertilizer placement was 8 cm. Two nitrogen applications, 60 kg ha^{-1} and 112 kg ha^{-1}, was applied as side-dress on the surface at 20 days after planting and 28 days after planting, respectively. The crop received supplemental irrigation applied via a sprinkler irrigation system. Irrigation amount received by the crop was measured with catch cans close to soil surface.

Crop phenology was monitored, such as number of leaves showing leaf tip, number of leaves with ligule, emergence date, 50% plants of plots at silking stage, and 75% of plants with black layer in the grains (black layer = physiological maturity). Five representative maize plants, in sequence, were collected for leaf and biomass determination. For each sampling, the soil surface area was also measured. Leaf area was measured with a leaf area meter (Licor meter). Dry weight was determined separately for leaves, stalk + tassel, cob, husk and grain. At harvest, grain yield (dry mass), leaves, stalk +tassel, and total aboveground biomass, final stand, grains per m^2, unit grain weight, ears per plant, ears per m^2 and harvest index were determined.
All data were collected with four replications.

Soil Data
Soil data are from nine replicated samples collected at the experimental area. Undisturbed 100 cm^3 soil samples were collected for bulk density, saturated hydraulic conductivity and water retention. Drained upper limit was considered volumetric water content in equilibrium with -10 kPa. Lower limit was considered volumetric water content in equilibrium with -1500 kPa. Total soil saturation was estimated with soil bulk density and soil particle density. Saturated hydraulic conductivity test was done in the lab. Disturbed soil samples were collected to determine standard soil physics and fertility tests (texture, particle density, total nitrogen, organic carbon concentration, pH in water). Some soil samples were also collected for initial soil conditions in terms of organic carbon and pH only.

A soil nitrate adsorption coefficient (SADC in the DSSAT soil file) was set for sub-surface layers as follows: 70cm = 0.3; 90cm=0.5; 110=0.9. The coefficients were set to reduce deep nitrate leaching based on observed nitrate leaching data collected in drainage lysimeter. Adjustments were also previously made on crop root growth factor (SRGF) to make the model properly simulate soil water content by layers.

Data ownership statement
The data were collected by Camilo L. T. Andrade (camilo@cnpms.embrapa.br), a researcher at Embrapa Maize and Sorghum. Data have not been published yet and can only be used in the scope of this AgMIP workshop.

References

OMETTO, J.C. **Bioclimatologia Vegetal**. São Paulo: Ceres, 1981. 400 p.

PANOSO, L.A.A.; RAMOS, D.P.; BRANDÃO, M. **Solos do campo experimental da Embrapa Milho e Sorgo**: suas características e classificação no novo sistema brasileiro. Rio de Janeiro: Embrapa Solos, 2002. (Embrapa Solos. Boletim de Pesquisa e Desenvolvimento, 5).

B. Model Calibration – Maize Models

1. Calibration and Validation of CERES-Maize Model for Sete Lagoas, Brazil:

Simulation was set to start 3 months prior to crop sowing in order to allow the model to properly simulate a bare soil water balance. CSM-CERES-Maize genetic coefficients were adjusted to minimize the RMSE and maximize d-stat statistics when comparing simulated and observed data for phenological phase durations, number of leaves, LAI, aboveground biomass and grain weight. Model verification was also done with data obtained in an independent trial carried out at Embrapa Maize and Sorghum for the same cultivar. No soil water content monitoring was done for the verification trial.

2. Setting Inputs and Calibrating Parameters of APSIM-Maize for Sete Lagoas, Brazil:

Climate data: APSIM compatible met file was created using observed data on rainfall, maximum temperature, minimum temperature and solar radiation from the experimental site.

Soil data: Soil data used was from DSSAT soil file provided by Camilo L. T. Andrade. Saturated soil water content, drained upper limit and wilting point moisture contents of various horizons, organic carbon content and particle size distribution are all based on the measurements made on soil from the experimental site. To this extent, the DSSAT soil file was similar to APSIM requirements. However, observed data to define air-dry moisture limit, curve number bare soil (CNbare), curve number reduction with cover (CNred), fraction of soil cover (CNcov) at which CNred is maximum, CONA, U and slope of the plot were not available. For these variables we used either model default values or estimates derived by comparison with similar soils and by experience. The crop specific lower limits of available moisture for maize were set to lower limits defined by moisture measurements at -1500 kPa.

Management: An operations file for sowing, fertiliser application and irrigation was created by specifying the date on which the operation was carried out along information on amount of input and method used.

3. Setting Inputs and Calibrating Parameters of STICS-Maize for Sete Lagoas, Brazil:

Climate data: STICS-compatible meterological file was created using observed data on rainfall, maximum temperature, minimum temperature and solar radiation from the experimental site.

Soil data: Soil data used was from DSSAT soil file provided by Camilo L. T. Andrade, which was based on the measurements made on soil from the experimental site: (1) dry bulk densities, (2) organic carbon content, along with the (3) saturated, (4) drained upper limit and (5) wilting point moisture contents of various horizons expressed in gravimetric water content. STICS requires the initial soil profile to be divided into a maximum of five horizons. In this case, the soil profile was divided into five horizons (0-5; 5-10; 10-30, 30-70, 70-110 cm) having initial values of the five previously described soil parameters. For other needed soil parameters, we used either model default values or estimates derived by comparison with similar soils and by experience.

Crop Phenology Data and Model Calibration: Three variety-specific variables were optimized through an iterative process by matching model simulated phenology with observed phenology. First, two parameters, DURFVIEF : (maximal life span of adult leaf) and CROIRAC (growth rate of the root front) were optimized though the observed yield biomass. Secondly, the parameter NBGRMAX (maximum number of grains) was optimized through the observed grain yield. For the species-specific variables, we used model default values.

Simulations of Time-Series Growth and Final Yield: The dry matter accumulation in total crop, grain yield, and leaf area index were simulated relatively close to observed, with minimal parameterization of APSIM or STICS, other than setting the crop phenology and substituting for missing soil traits as described above. These results are not available for this report (not published yet), but were visually shown in the AgMIP-Brazil workshop and simulated time-series outputs of total crop biomass and grain mass were relatively comparable for the three maize models, APSIM, CERES, and STICS.

4. Sensitivity Analysis to Climatic Factors for Three Maize Crop Models:

Setting up for APSIM Maize Model: Performance of maize in response to changes in temperature, CO_2 concentration, amount of rainfall, nitrogen fertilizer and sowing date was carried out by changing one parameter at a time from the baseline scenario which reflects the actual historical conditions for the experimental site. The "*climate control*" module was used to set incremental changes in temperature and rainfall. Different atmospheric CO_2 concentrations were specified directly in the crop XML file. Simulations were carried out by incorporating appropriate changes to "operations" file based on the conditions defined in AgMIP protocols.

Setting up for CERES-Maize Model: Performance of maize in response to changes in temperature, CO_2 concentration and amount of rainfall, was carried out using the Environmental Modifications section. N fertilization rates and sowing dates were separately changed in the File X.

Setting up for STICS-Maize Model: Performance of maize in response to changes in temperature, amount of rainfall, nitrogen fertilizer and sowing date was carried out by changing one parameter at a time from the baseline scenario which reflects the actual historical conditions for the experimental site. Specific climate and crop management input date files were generated in order to set incremental changes in temperature and rainfall and date of sowing, respectively. It was not possible in the current configuration of the STICS model to simulate the CO_2effect. In the model, atmospheric carbon dioxide has concomittent effect on conversion efficiency and stomatal conductance. In this case, STICS adopted the formalization proposed by Shuttleworth and Wallace which requires non available climatic data (daily vapour pressure and speed wind).

C. Results of Sensitivity to Climatic Factors – Maize Models

Temperature effects (see results in Figure 1):

1. For the APSIM model, the increase in temperature led to a decrease in grain and biomass yield and the grain yield decline was more than 50% with an increase by 9^0C fom the current levels. CERES-Maize yield similarly declined in yield and biomass with the highest temperature levels, although showing surprising insensitivity of yield and biomass for -3^{o}C, 0, and +3^{o}C condition. STICS showed decline in grain yield as temperature was increased

from +0 to +9 ^{o}C, although its temperature sensitivity was less than APSIM. The STICS model showed a modest decline in total crop biomass with rising temperature that was less than the response of CERES or APSIM, but attributable in part to life cycle effects.

2. For APSIM, days to maturity and anthesis declined sharply upto six 6^{o}C increase from current levels and with a 9^{o}C increase in temperature a slight increase in days to anthesis and maturity was noticeable. CERES also showed decline in days to maturity and anthesis over the whole range of rising temperature, but the decline was not as sharp as for APSIM. STICS had a very similar decline as CERES from -3 to +3^{o}C, but had sharply longer time to anthesis and maturity going from +6 to +9^{o}C. In fairness to model developers, there are no data on effects of super-high temperature on phenology development of maize, other than a few hints of increase in time to maturity and anthesis with very high temperature so there is a good possibility that STICS is acceptable for its response..
3. The models were quite different in their predicted effect of temperature on maximum LAI (data not shown). For APSIM, the maximum LAI was highest at -3^{o}C, and declined sharply with increasing temperature up to 6^{o}C from current levels and then plateaued. CERES increased slightly in maximum LAI going from -3 to +3^{o}C, and then began to decline rapidly, reaching relative LAI of 0.27 at +9^{o}C. STICS gradually increased LAI all the way up to the highest temperature.
4. Relative season-long evapotranspiration of all three maize models declined similarly and slowly with increasing temperature; however, most of this effect was associated with the reduction in the crop life cycle with rising temperature. In fact, model differences in the relative reduction in ET with rising temperature were linked to model-effect on life cycle, with least reduction in seasonal ET for STICS associated with less temperature-induced shortening of life cycle for STICS. The seasonal ET was reduced less than crop life cycle, indicating that warmer temperature increased daily ET as expected, using the Priestley-Taylor equation to predict ET (for CERES). It is re-assuring to note that APSIM gave a similar relative ET response, because it uses a different mechanism to predict ET, based on reduction in RUE as temperature rises, so biomass accumulation will be lower (as seen in the figure) and lower transpiration (via transpiration efficiency) from daily biomass produced.
5. Temperature effects on grain number mostly mirror the effects of temperature on grain yield for the different models. The one exception is that grain number for CERES-Maize increased with +3C in contrast to the other models.
6. Effect of rising temperature on total plant N mostly mimics the effect of temperature on total crop biomass, with one notable exception. For the STICS model, plant N increased consistently with rising temperature, even while total biomass declined.

Effect of atmospheric carbon dioxide concentration (no figures shown):

1. For APSIM, the grain and biomass yields increased by about 13.6 and 11.0%, respectively, with increase in atmospheric CO_2 concentration from 350 to 750 ppm. CERES-Maize showed smaller increases of about about 2.5% increase in yield and 2.0% increase in biomass with doubling of CO_2. [Note: K. J. Boote re-parameterized CO_2 sensitivity of the maize model 2 years ago to give about 4.5% yield response to doubled CO_2. But this response of CERES-Maize is less than expected and merits further investigation). The real answer is between the two models (K. J. Boote indication based on limited data). STICS simulations of CO_2 response were not possible in the current configuration of the model.
2. CO_2 concentration had no effect on days to maturity or days to flowering for either APSIM or CERES-Maize. For APSIM, the maximum LAI attained and grain number showed an increase which is similar to the response observed for grain and biomass yields. CERES-Maize indicated a slightly decrease in LAI and a slightly increase in grain number as a function of CO_2 concentration rise.

3. Both APSIM and CERES had relatively constant total crop nitrogen with rising CO_2. For APSIM, this relatively constant crop N despite higher biomass yield may need further investigation (per APSIM modelers).
4. A significant decline in transpiration was simulated with increase in the atmospheric CO_2 concentration for both models, although the APSIM model had a 16.4% decline and CERES a 5.3% decline in transpiration with doubled CO_2 (350 to 750 ppm). Two recent controlled-environment papers reported reduction in transpiration of 18% for maize and sorghum under doubled CO_2 (360 to 720 ppm). So the models differ in their response and CERES-Maize transpiration reduction with CO_2 appears to be too conservative. Further investigation is also needed because CERES predicted transpiration is 40% greater than that of APSIM.

Effect of changes in rainfall (no figures shown):

1. Maize showed limited response to rainfall since the crop was irrigated.
2. The magnitude of increase in grain and biomass yields and other parameters with increased rainfall was very small and the trend followed expected directions (small increase for the APSIM model). The small rise in ET response for APSIM confirms that the APSIM-simulated crop was slightly water-limited. For CERES, there was actually a small decrease in yield, biomass, and LAI with rising rainfall. Possibly, N leaching contributed to this outcome. STICS showed minimal responses to rainfall variation, indicating that water was not limiting and possibly N was also not limiting.
3. There were no effects on phenology.

Effect of planting date (no figures shown):

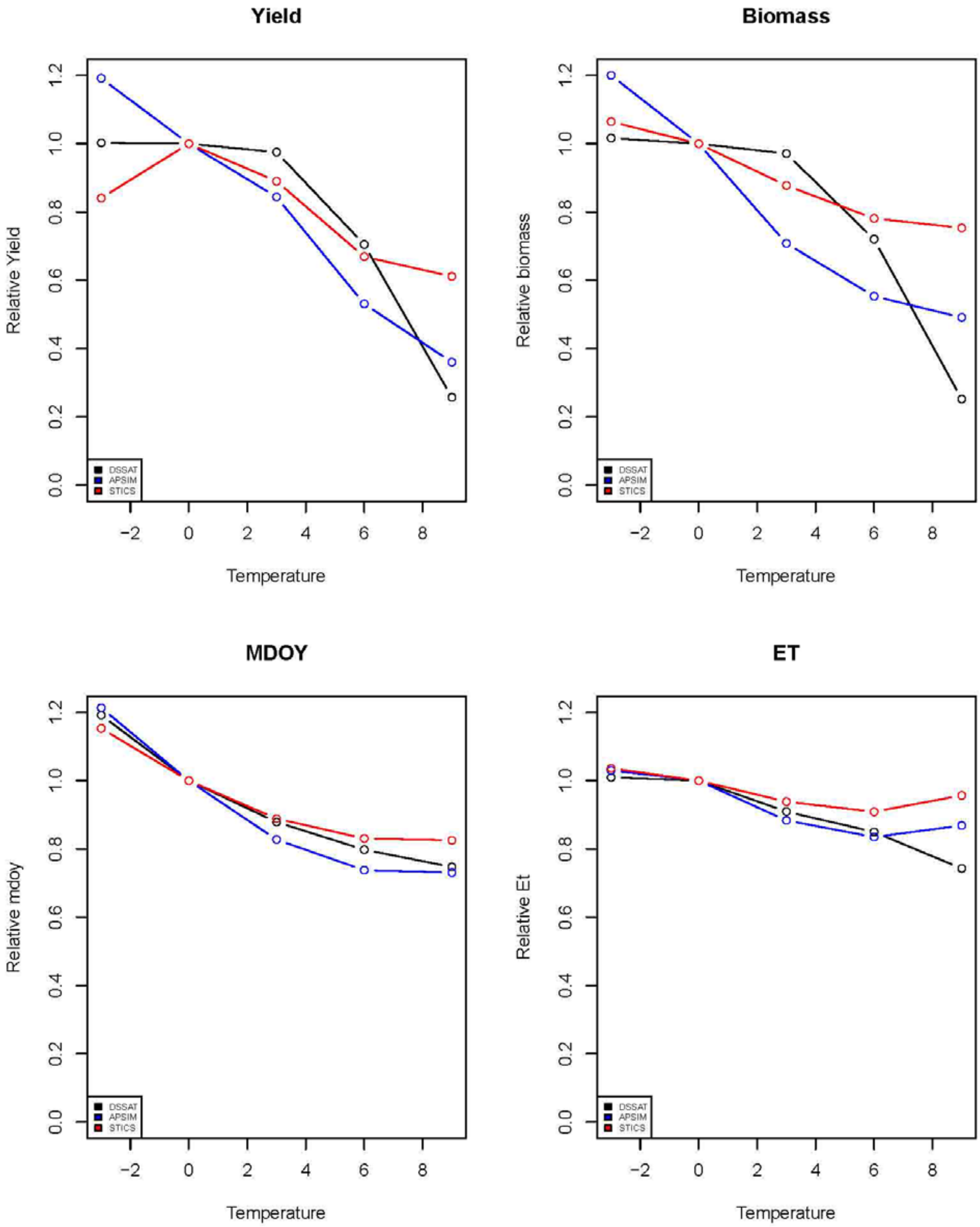
1. For both models, the default (February 21st) sowing date was best and yield was less for earlier or later sowing dates. For APSIM, delayed planting reduced grain yield by 24% and biomass by 14%. For CERES, delayed planting reduced grain yield by 28% and biomass by 12%. It is important to appreciate what contributed to this decline with later sowing. Cooler temperature and lower solar radiation are possibilities associated with delayed planting. The crop life cycle was extended (evidence of cooler temperature), but that should normally have a positive effect on yield as suggested by temperature sensitivity analysis. An evaluation of the weather data indicates that lower solar radiation is the principle cause.

Effect of N fertilizer (no figures shown):

1. The maize models differed in their yield response to N fertilization, with APSIM responding more sharply to N fertilizer and then saturating quickly. CERES and STICS were similar to each other. The biomass response to N fertilizer was relatively similar among the models. All the models predicted fairly equally about 25% yield potential and 30-45% biomass potential with zero fertilizer N, which indicates native N mineralization of the soils and initial conditions were well-informed.
2. The models differed in LAI response to N fertilizer. APSIM had almost the same LAI at all N fertilizer levels, being at 90% of maximum LAI at zero N, whereas the LAI of CERES was very responsive to N, being at 32% at zero N. STICS was intermediate.
3. The models showed no sensitivity of anthesis or maturity date to N fertilization. This was expected based on our knowledge of the models having no N effects on phenology (although N deficiency is known in reality to delay anthesis, and accelerate maturity).
4. Crop N uptake was increased with increased N fertilization, with similar responses across the three models. APSIM had the lowest N uptake at zero N fertilizer, which is puzzling because its LAI was insensitive to N fertilization. This should be investigated.
5. The seasonal evapotranspiration in response to N fertilization was different across the models. STICS very slightly reduced ET at very low N. CERES had a progressively lower ET with lower N fertilization, with 14% less ET at zero N. Most of this effect is from the LAI effect on ET. APSIM had the strongest reduction in ET (by 30%) at zero N

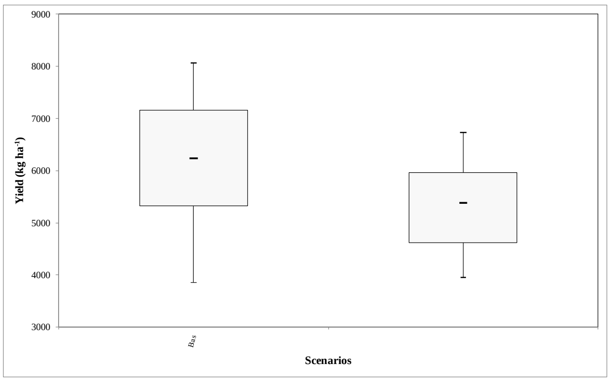
fertilization, which again is somewhat surprisng, as the LAI was barely reduced (15%). The cause is related to the method of predicting transpiration in APSIM (model predicts photosynthesis (biomass) first, then computes transpiration based on a WUE efficiency coefficient and relative humidity). Low N caused lower biomass, hence less transpiration.

Figure 1. Yield, Biomass, Days to Anthesis, and Seasonal Evapotranspiration of DSSAT, APSIM, & STIC maize models in response to temperature at Sete Lagoas, Brazil.



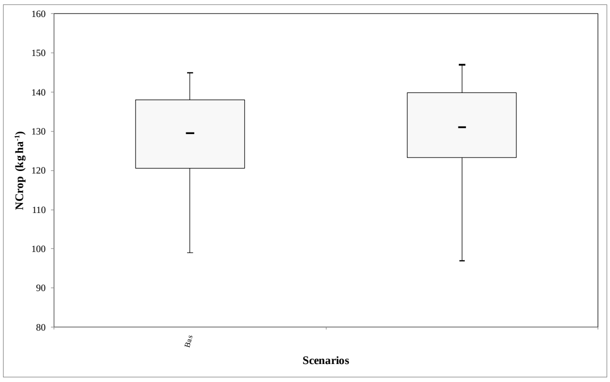
D. Impact of Future Climate Scenarios – Maize Models

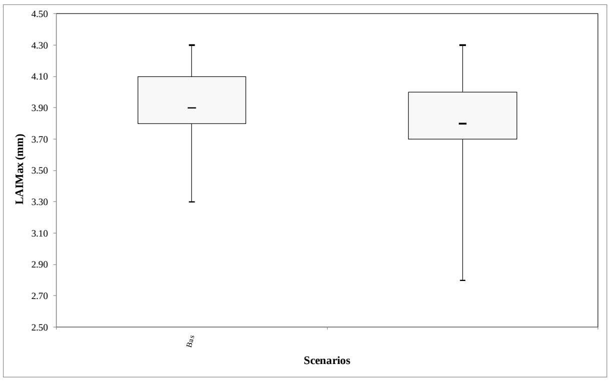
1. Future climate scenarios (CERES): This was carried out maize for Sete Lagoas, MG, Brazil location using two sets of climate data, one for current climate and the other for median future scenario generated by AgMIP climate group. Both datasets are for 30 years. DSSAT and APSIM runs were setup using conditions similar to those defined in the baseline scenario.

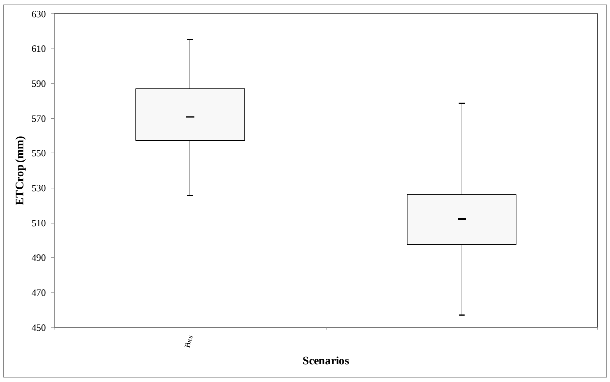


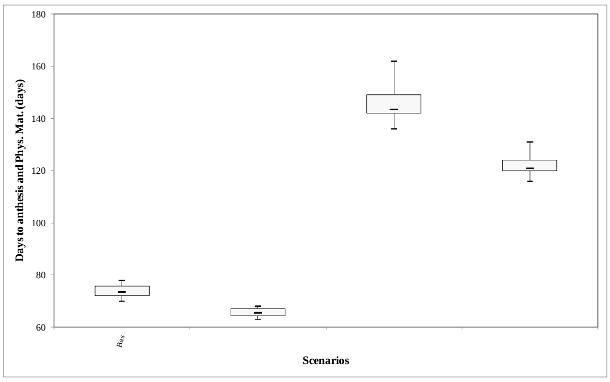
CERES-Maize

1. Mean yield and crop biomass tended to be reduced in the future climate scenario with smaller inter-annual variability;
2. Crop N tended to increase slightly and maximum LA tended to decrease slightly in future scenario**;**
3. Days to anthesis and physiological maturity were considerably shortened and accordingly reduce crop ET.

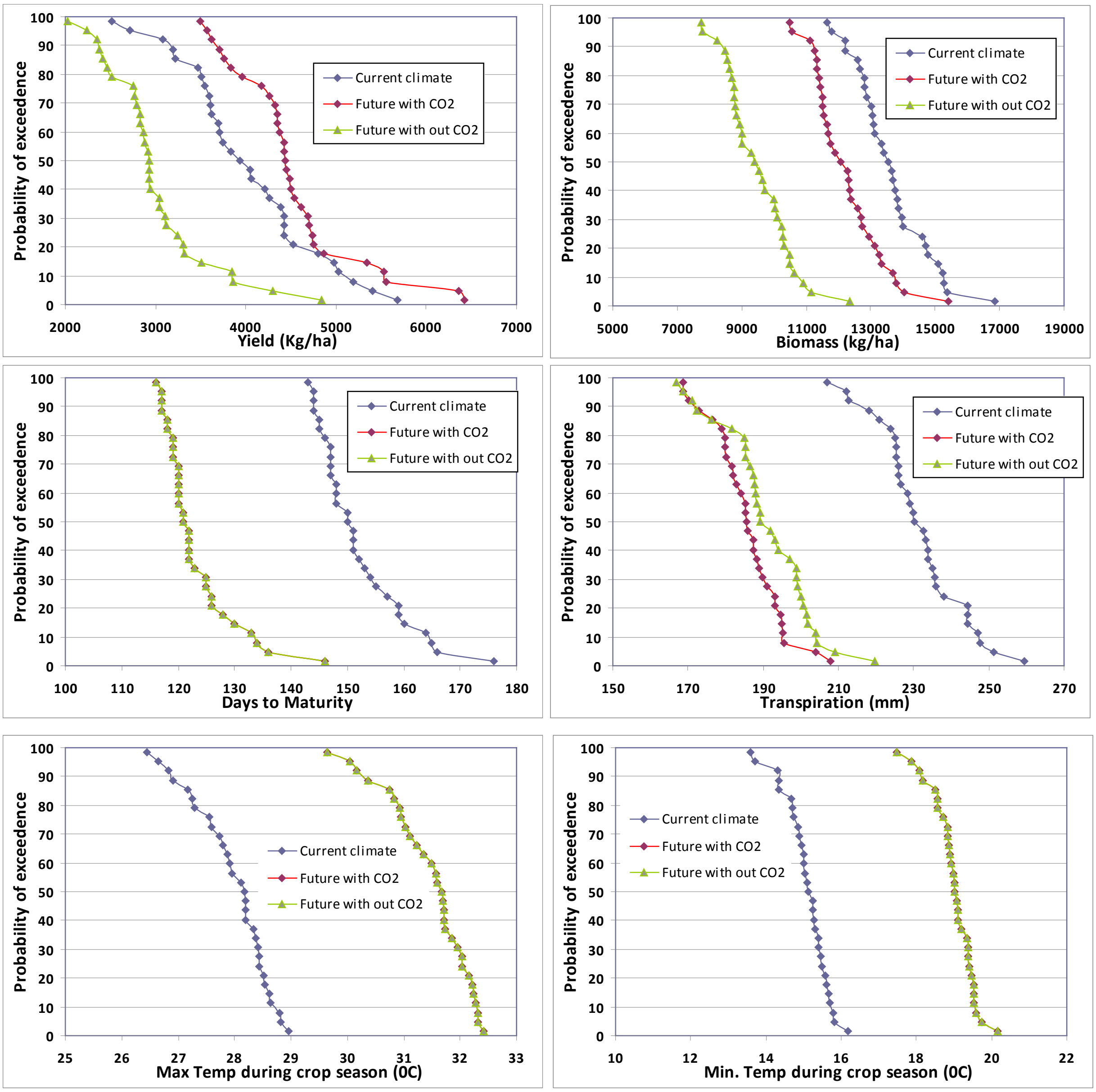




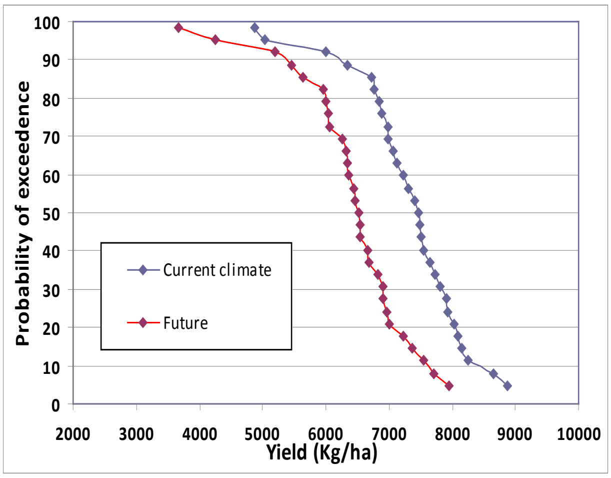


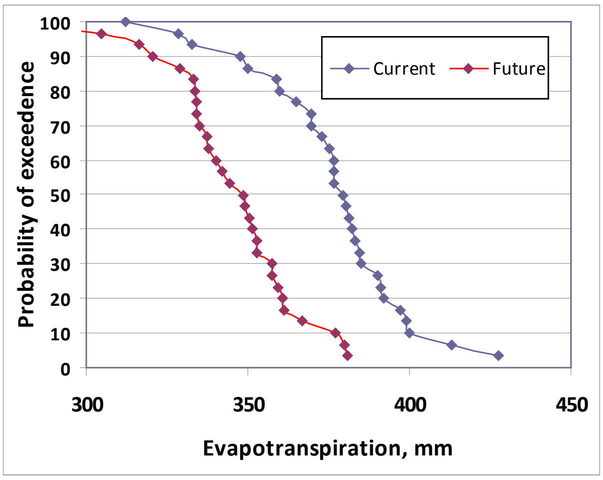


2. **Future climate scenarios (APSIM):** This was carried out for the Seta-Lagous using two sets of climate data, one for current climate and the other for median future scenario generated by AgMIP climate group. In the examples below, APSIM presented grain yield, total biomass, transpiration, and life cycle (and other outputs not shown) as probability of exceedance graphs for baseline, future scenario, and future scenario with elevated CO_2. This is alternate way of presenting the results compared to box and whisker plots. The future climate for this location had future Tmax about 3 C warmer and Tmin 2C warmer, with little rainfall change. The result of future climate was a shorter life cycle by 25-30 days, with lower yield and biomass if without CO_2 rise, but with biomass and grain yield (recovered or equivalent to current climate) under future climate if CO_2 rise was included. Transpiration was reduced under future climate because of shorter life cycle, and because of elevated CO_2 when that factor was included.



3. **Future climate scenarios (STICS):** This was carried out for the Seta-Lagous using two sets of climate data, one for current climate and the other for future scenario generated by AgMIP climate group. In the examples below, grain yield and evapotranspiration simulated by STICS are presented. Actually the STICS model in this configuration did not predict CO2 effects on RUE or transpiration, so the effects are primarily related to shorter life cycle.





II. Data, Model Adaptation, and Sensitivity Analysis with two Sugarcane Crop Models

Crop: Sugarcane

Models: APSIM Sugarcane and DSSAT/CANEGRO

People: Fabio Marin, Abraham Singels, and Peter Thorburn.

A. Data Description – Sugarcane – Fabio Marin - Brazil

DSSAT/CANEGRO (Singels et al., 2008) was parameterized and evaluated using data from RB72-454 cultivar, collected in one location in Brazil (Suguitani, 2005) (Table 1). The experiment received adequate N, P and K fertilization and regular weed control and was planted using healthy cuttings with 13 to 15 buds m^{-2}. Row spacing varied from 1.4 m to 1.5 m. The datasets had two treatments (irrigated and rainfed). The irrigated treatment received water by sprinkling and the irrigation schedule was determined by tensiometer monitoring to maintain the soil layers close to field capacity to a depth of at least 1 m.

Table 1. Source of experimental data used and main soil and climate characteristics.

Site	Planting and Harvest Dates	Cultivars	Crop Cycle[1]	Climate[2]	Treatments
Piracicaba/SP, 22°52'S, 47°30'W, 560m asml	10/29/2004 and 9/26/2005	RB72-454 SP83-2847 NCo376	Plant cane	21.6°C, 1230mm, CWa	1) Irrigated, 2) Rainfed

[2] Respectively: mean annual temperature, annual total rainfall, Koeppen Classification

The cultivar RB72-454 formerly was one of the most widely planted in Brazil. During recent years, however, orange rust has arrived in Brazil, greatly affecting this cultivar. In the last 3 years, this cultivar has been replaced by new resistant genotypes. At the time of the experiments, there was no orange rust occurrence in the field. RB72-454 is late maturing with high cane and sucrose yields when grown either as a plant crop or ratoon. The variety is able to produce high yields even in poor soils and diverse climates. It was also typically used as the standard cultivar in biometric and yield trials in Brazil, and is found in sugarcane collections around the world.

Detailed crop growth variables including green leaf area index (LAI), stalk population, stalk and aerial dry mass; and number of green leaves were collected at 4-5 week intervals over the cycle (Suguitani, 2005). Root length density, root depth and root mass were also collected, for cultivar RB72-454 (Laclau, 2005), using the experimental procedures described in Laclau and Laclau (2009).

Soil Data

Soil is classified as Latossolo Vermelho-Amarelo (Soil Classification by Brazilian Soil Classification System, Embrapa, 1999) or as Typic Hapludox by the equivalent nearest US Soil Taxonomy. As soil water parameters required in the models (Table 1) were not measured, the values of LL, DUL, and SAT were defined using the pedotransfer functions provided by Tomasella et al. (2000). The estimated values were checked against measured pressure plate data from Embrapa (1981) and Radambrasil Project (1973-1986) from multiple locations at each site, with good agreement. The input data for PTF were provided by Suguitani (2005) and Laclau (2005). Same values were used for APSIM (Table 2), with the Sugar LL assumed to be the same as AirDry.

Table 1. Soil properties input for DSSAT/CANEGRO model.

Layer Depth	LL, Lower limit, $cm^3\ cm^{-3}$	DUL, Upper limit drain., $cm^3\ cm^{-3}$	SAT, Upper limit sat., $cm\ cm^{-3}$	Root Growth Factor
20	0.200	0.310	0.480	1.000
40	0.230	0.330	0.480	0.810
100	0.240	0.340	0.490	0.555
450	0.250	0.350	0.490	0.320

Table 2. Soil properties input for APSIM-Sugarcane model.

Depth	Air Dry (mm/mm)	LL15 (mm/mm)	DUL (mm/mm)	SAT, (mm/mm)	Sugar LL (mm/mm)	Sugar KL (/day)	Sugar LL
20	0.200	0.200	0.310	0.480	0.200	0.15	1.0
40	0.220	0.220	0.330	0.480	0.220	0.15	1.0
100	0.220	0.220	0.340	0.490	0.220	0.10	0.8
450	0.210	0.230	0.350	0.490	0.210	0.08	0.6

B. Model Calibration – Sugarcane Crop Models

1. Calibration and Validation of DSSAT/CANEGRO Model for Brazil:

Simulation was set to start 2 months prior to crop sowing in order to allow the model to properly simulate a bare soil water balance, and initial soil water conditions were set equal to the lower limit soil water. However, the calibration of cultivar traits (Table 3) was done assuming the initial soil water at field capacity. The Priestley-Taylor method was used to estimate reference evapotranspiration. DSSAT/CANEGRO genetic coefficients were adjusted to minimize the RMSE, maximize d-stat and modeling efficiency statistics when comparing simulated and observed data.

Table 3. Cultivar parameter values for NCo376 and RB72454 used in DSSAT/CANEGRO.

Parameter	**NCo376**	**RB72454**
MaxPARCE	9.9	12.85
APFMX	0.88	0.904
STKPFMAX	0.65	0.642
SUCA	0.58	0.565
TBFT	25	25
LFMAX	12	10
MXLFAREA	360	600
MXLFARNO	14	16.91
PI1	69	70.8
PI2	169	116.6
PSWITCH	18	21
TTPLNTEM	428	400
TTRATNEM	203	203
CHUPIBASE	1050	448
TT_POPGROWTH	600	628.3
MAX_POP	30	20
POPTT16	13.3	8.4
LG_AMBASE	220	220
dPERdT**	0.176	0.276

2. Setting Inputs and Calibrating Parameters of APSIM-Sugarcane for Brazil.

Climate and Soil data for APSIM model (Keating et al. 1999) were taken from DSSAT/CANEGRO files. APSIM cultivar specific coefficients were adjusted to minimize the RMSE, maximize d-stat and modeling efficiency statistics when comparing simulated and observed data. It was done using the 'visual by eye-fit'. The adjustments were done based on Q117 cultivar coefficients available in APSIM-Sugarcane. Parameters such as leaf size, cane_fraction and tiller_leaf_size (Table 4) were adjusted taking into account the observed data (Marin et al., 2011). This cultivar was selected as, like RB72-454, it was very widely grown in Australia and well characterised for APSIM (Keating et al., 1999; Thorburn et al., 2005). But it has been replaced by more modern and disease varieties over the past 15 years. Management operations file for sowing, fertiliser application and irrigation was created by specifying the date on which the operation was carried out along information on amount of input and method used. The calibration (Table 4) was done assuming the initial soil water at field capacity, assuming 12 plants/m^2 at planting and 120 kg/ha fertilizer application, which resulted in any N stress along the cycle.

Table 4. Crop XML cultivar parameter for Q117 and RB72454 used in APSIM-Sugarcane.

Parameter	RB72-454					Q117				
leaf_size	1500	75000	65000			1500	55000	55000		
leaf_size_no	1	14	20			1	14	20		
cane_fraction	0.65					0.7				
sucrose_fraction_stalk	1	0.55				1	0.55			
stress_factor_stalk	0.2	1				0.2	1			
sucrose_delay	0					0				
min_sstem_sucrose	800					800				
min_sstem_sucrose_redn	10					10				
tt_emerg_to_begcane	1050					1900				
tt_begcane_to_flowering	6000					6000				
tt_flowering_to_crop_end	2000					2000				
green_leaf_no	10					13				
tillerf_leaf_size	1	1	1.5	2	1	1.5	3	2.5	1	1
tillerf_leaf_size_no	1	4	10	16	26	1	4	10	12	26

3. Simulated and observed data for both models

Both models underestimated rainfed aerial and stalk dry mass, although DSSAT/CANEGRO was closer than APSIM. For the irrigated treatment, simulations resulted in different patterns between the two models. DSSAT/CANEGRO gave higher values of aerial dry mass than observed ones, while APSIM underestimated. Both models came closer to measured values for stalk in the irrigated treatment.

Based on this short comparison, one could point the need for further calibration/parameterisation effort in both models. The sugarcane parameters used in APSIM were basically the same as those of the Australian variety Q117 (Table 4), with no modification of RUE and canopy structure, such was done for DSSAT/CANEGRO (Table 3). Also, by comparing the rainfed and irrigated results (i.e. the small differences between yields in Table 5), one would highlight the soil parameterization as another issue needing further investigation, as the rainfed simulations are indicating a greater soil water holding capacity than those simulated by the pedotransfer function used (Tables 1 and 2).

Table 5. Observed and simulated values of aerial dry mass and stalk mass at harvest for rainfed and irrigated treatment.

	Aerial dry mass (t ha^{-1})		Stalk dry mass (t ha^{-1})	
Data source	Irrigated	Rainfed	Irrigated	Rainfed
Observed	61	65	39	39.5
APSIM	52.94	44.80	39.96	34.66
CANEGRO	66.20	55.60	42.20	35.40

4. Setting up for APSIM Sugarcane Model: Performance of sugarcane in response to changes in temperature, CO2 concentration and amount of rainfall was carried out by changing one parameter at a time from the baseline scenario which reflects the actual historical conditions for the experimental site. The "*climate control*" module in APSIM was used to set incremental changes in temperature and rainfall. Different atmospheric CO_2 concentrations were specified directly in the crop XML file. The management conditions were the used for the parameterization process.

5. Setting up for DSSAT/CANEGRO Model: Performance of sugarcane in response to changes in temperature, CO2 concentration and, amount of rainfall was carried out using the

Environmental Modifications section (for temperature, CO_2, and rainfall). The management conditions were the used for the parameterization process, including the cycle length (330 days).

C. Results of Sensitivity to Climatic Factors –Two Sugarcane Models

1. Effect of atmospheric carbon dioxide concentration:

Both models simulated increase in aerial dry mass, stalk mass and LAI. APSIM simulated an average increase of 4.4% per 100 ppm and DSSAT/CANEGRO simulated an average increase of 2.5% per 100 ppm (Figure 1a). For APSIM, simualtions for 350ppm and current scenarios resulted the same. Both models had the identical responses for stalk and aerial biomass relative to CO2. In APSIM CO2 responses are due to changes in RUE and water use efficiency, reducing the water stress.

DSSAT/CANEGRO has no direct response simulated to photosynthesis, but only the transpiration responds to CO2 concentration by increasing the leaf resistance to water vapor loss, leading to higher water use efficiency and reduction of water stress.

2. Effect of changes in rainfall:

Sugarcane showed limited response to increased rainfall (+30%) even though the crop was rainfed (Figure 1b). This result might be caused by the high soil water retention and rooting depth (4.5m) for the datasets simulated. Both models simulated increases of LAI, aerial dry mass and stalk mass as rainfall increased. The average increase was 10% for APSIM and 7% for DSSAT for a 30% change in rainfall, ascribed to increased soil water availability, reducing water stress and higher LAI and biomass (Fig. 1b) . DSSAT/CANEGRO showed slightly higher sensitivity to the reduction of rainfall than APSIM. Simulated LAI by DSSAT/CANEGRO was reduced by nearly 25% as rainfall decreased 30%.

3. Temperature effects:

APSIM simulated a decrease in areal dry mass, stalk dry mass and leaf area index (LAI) with increasing temperature at all levels (Fig. 1c). In contrast, DSSAT/CANEGRO simulated an increase in aerial dry mass and stalk mass with increasing temperature up to +6^{o}C, followed by a decrease at +9^{o}C. This unusual response needs further investigation and confirmation. The temperature range of 12^{o}C led to a range in biomass of 40% in APSIM. The corresponding range in yields from DSSAT/CANEGRO was 47%, although its response was in the opposite direction. These differences in model responses to temperature need to be evaluated against good temperature transect data which may be difficult to find, although limited temperature-gradient greenhouse data (of L.H. Allen) suggests rising sugarcane biomass with above ambient temperature.

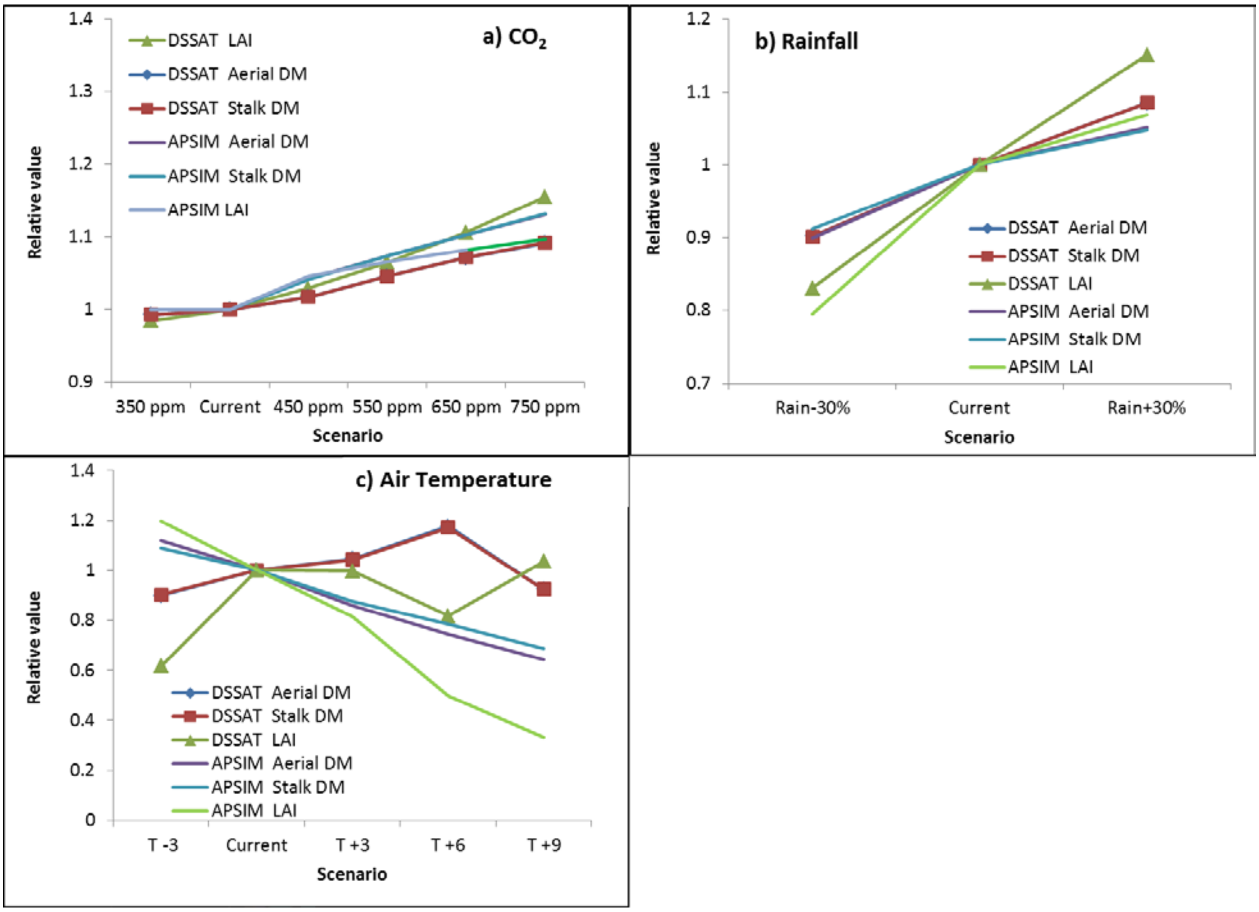


Fig 1. Relative response to CO_2 (a), rainfall (b) and air temperature (c) changes on APSIM-Sugarcane and DSSAT/CANEGRO for aerial dry mass, stalk dry mass and LAI.

D. Impact of Future Climate Scenarios Compared to Baseline –Two Sugarcane Models

1. Future climate scenarios: This was carried out using two sets of climate data, one for current climate and the other for median future scenario generated by AgMIP climate group. Both datasets are for 30 years. APSIM runs were setup using conditions similar to those defined in the baseline scenario. Figure 2d shows the relative difference between baseline and future climate scenarios, highlighting that all climate variables were increased compared to the baseline. Maximum and minimum temperatures were increase nearly 5°C, CO2 was elevated to the double current conditions and rainfall was increased by 15%. It is important to emphasize the simulations used a 330-day crop cycle, which does not well represent an “average” ratoon crop (often with 365 days cycle length).

Figures 2a and 2b show APSIM simulated lower yields, with higher variability and greater climate scenario effects than DSSAT/CANEGRO, likely related to the large LAI decrease simulated by APSIM. Also, it suggests air temperature as a driver in both models, but in an opposite way. The higher the temperature, the lower the crop biomass simulated by APSIM, and the inverse for DSSAT/CANEGRO.

DSSAT simulated a lesser decrease in LAI compared to APSIM, while there was increase in ET and biomass, and both variations were higher than ones simulated by APSIM for ET and aerial biomass. DSSAT/CANEGRO also simulated a reduction in sucrose yield.

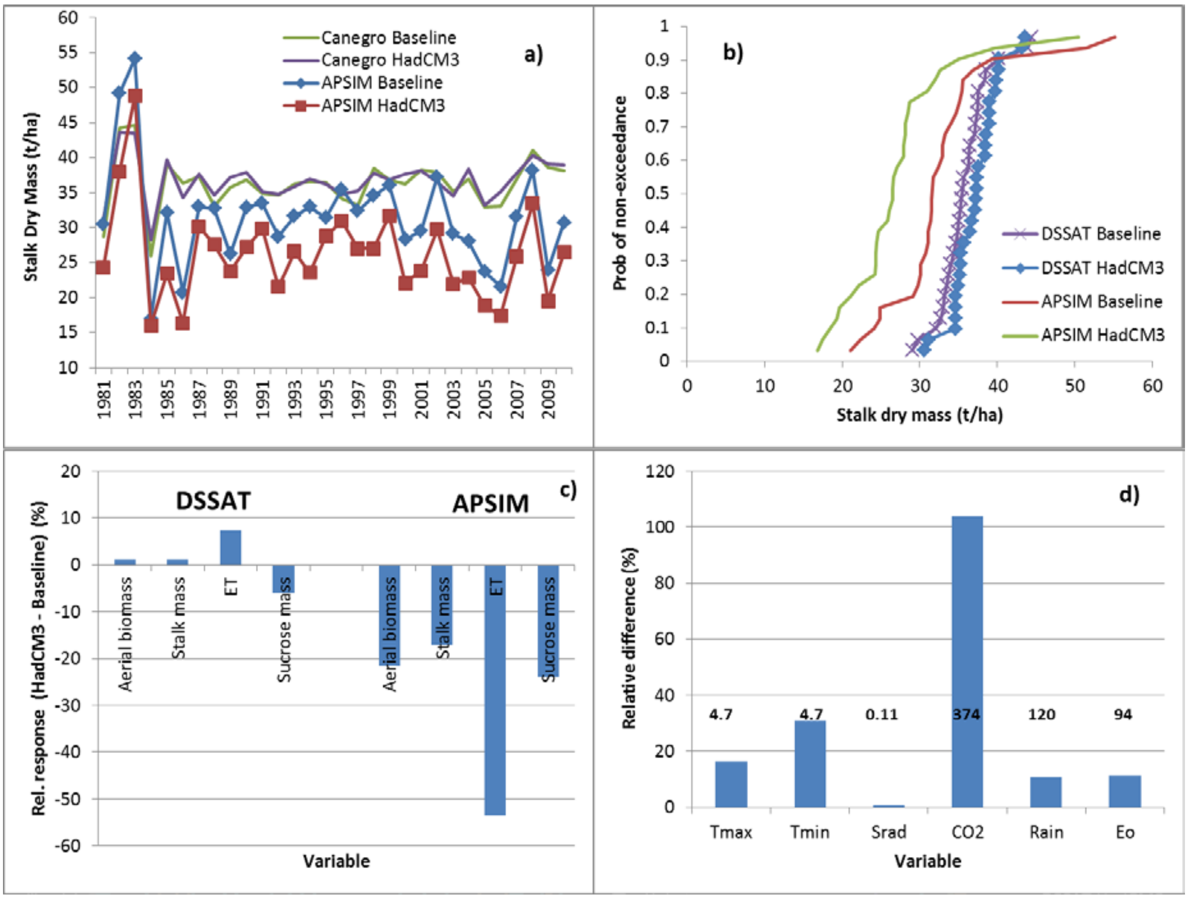


Fig. 2. Time variation of simulated stalk dry mass (SDM) by APSIM and DSSAT/CANEGRO (a) using baseline and future (HadCM3) climate scenario; the probability of non-exceedance for SDM simulated by both models (b); relative response of several variables for APSIM and CANEGRO (c); and the relative difference for baseline and future (HadCM3) climate scenario (d). Values close the bars in (d) indicates the absolute differences.

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III. Rice Crop Modeling Activities at AgMIP-South America Workshop Campinas, Brazil August 1-5, 2011

A. Data Description – Rice – Alexandre Bryan Heinemann

Data ownership and all simulations were conducted by:

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REPORT INFORMATION: CROP DATA
UPLAND RICE DATA Calibration data
Varieties: One cultivar BRS Primavera.
The trial was carried out at Embrapa Rice and Beans experimental station, located at Santo Antônio de Goiás, GO, Brazil, (Latitude 16.48 S; Longitude 49.3 W; Altitude 823m). The soil is classified as Oxisol.
The cultivar BRS Primavera was sown 5 cm deep, on February 21st 2009. Final crop stand was 143 plants per m-2. Fertilizer use consisted of 20 kg ha^{-1} of N, 120 kgha-1 of P_2O_5 and 60 kgha^{-1} of K_2O, at planting date. Fertilizer placement was 8 cm. Two nitrogen applications, 40 kgha^{-1} and 40 kgha-1, were done, side-dressing on the surface at 30 and 56 days after planting. The crop do not received supplemental irrigation.
Complete Data Set for Calibration: Yield, Growth Biomass (Stem, Leaf and Total Aboveground Biomass); LAI; Soil moisture data (Diviner equipment – each 10 cm from 0.10 to 1.0 m; Leaf appearance rate; Phenology data; Effective root depth; Root distribution (Visual observation through soil profile)
UPLAND RICE DATA Validation data
Site Embrapa Rice and Beans (Lat -16.4667; Long -49.28) :
    Dates: 2009/2010 (water stress) and 2010/2011 (no water stress);
Site Porangatu (Lat -13.44, Long -49.14):
    Date: 2009/2010 (water stress, -LAI).
Data for Validation: Phenology (planting and flowering data) and Yield from UplandRice Multi-Trial Environment:
Site Embrapa Rice and Beans (Lat -16.4667; Long -49.28)
    Data: From 2005 to 2010
Site Sinop (Lat -11.98; Long -55.56)
    Data: 2 years;
Site Sorriso (Lat-12.54; Long-55.71)
    Data: 2 years;
Site Terezina (Lat -5.08; Long -42.8)
    Data: 2 years;
Site Vilhena (Lat -12.73; Long -60.15)
    Data: 2 years.

References about observed data and cultivar used in this report:

Lorençoni, R.; Dourado Neto, D.; Heinemann, A. B. 2010. Calibration and evaluation of the ORYZA-APSIM crop model for upland rice in Brazil. Revista Ciência Agronômica, v. 41, n. 4, p.

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Survey Upland Rice yield data

Historical yield data set of the Brazilian Geographic and Statistics Institute (IBGE, www.ibge.gov.br/home/) from 54 microregions in Brasil central from 1976 to 2006. This historical upland rice yield data set is collected from a network of cooperatives and farms and then organized by IBGE.

Reference:

Heinemann, A. B., Sentelhas, P. C. 2011. Environmental group identification for upland rice production in central Brazil. Sci. Agric. (Piracicaba, Braz.), v.68, n.5, p.540-547.

B. Model Calibration – Rice Crop Models

Calibration
Upland Rice Simulated with APSIM/Oryza and CERES-Rice

What needed to be done to get the model going? And what problems did we encounter?

- Protocol for collecting observed data, mainly phenological data (ex.: panicle initiation).
- The LAI for APSIM/Oryza during periods of water stress shows strange behavior. Code should be verified.
- The method used for APSIM/ORYZA to calculate number of grains and panicles per ha does not fit well for upland rice.
- For CERES-Rice we need to define whether calibration uses flowering date or Heading date.
- Both models had to be adjusted (water stress factors) in order to simulate Upland Rice.
- For upland rice crop the impact of water stress factor from CERES-Rice on phenology should be re-evaluated. The water stress impact on phenology on upland rice is not the same as flooded rice. Upland rice grows in unsaturated soils. It makes it difficult to fit the observed and simulated phenology (*CERES-Rice delays terminal initiation under water stress, a strategy that may not be correct, K. Boote has had experience with rainfed rice in India*).

Was this easy?
- It depends on the desire of modeling developers.

Was any information missing?

Methods: Comparison between APSIM/Oryza and CERES-Rice.
Baseline APSIM/Oryza CO2 = 340 ppm;
Baseline CERES-Rice = 380 ppm.
N levels: 0 (0 kg of N), 25 (25 kg of N), 50 (50 kg of N), 100 (100 kg of N) and 150 (150 kg of N). The default N application is a total of 100 kg of N (20 kg of at planting date; 40 kg of N at 30 DAE and 40 kg of N at 58 DAE).

C. Results of Sensitivity to Climatic Factors – Rice Models

Temperature Effect: Both models simulated a decrease in days to anthesis and maturity as temperature was increased from -3C to +3C; however above +3C, APSIM-ORZYA had delayed time to anthesis and maturity. CERES-Rice had the shortest time to anthesis and maturity at +6C, and a small delay or longer time at +9C. Above the +3C, the crop cycle of APSIM-ORYZA increased instead of decreased as function of an increase on mean temperature. Alex suggested that the equation used for APSIM/Oryza model to calculate heat Unit (HU) overestimates the HU penalization for low latitude locations (*however, Boote and colleagues have data that actually supports slower progression of rice at very high temperature, so we need to compare the models to real data and confirm the origin of functions in ORYZA*). None of the models showed sensitivity of phenology to CO2, water, or N fertilization

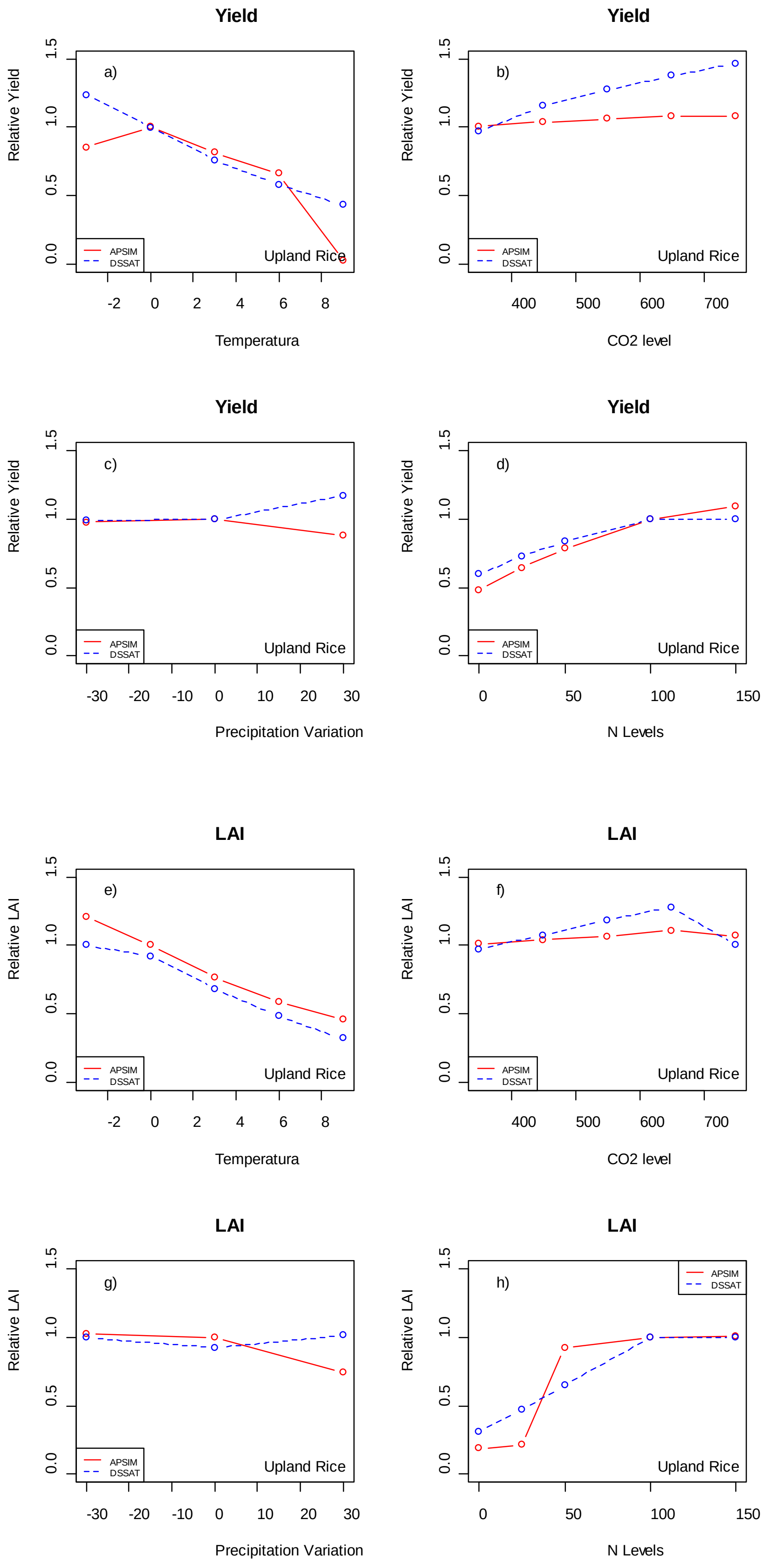
The two rice models had fairly similar behavior for yield response to temperature between 0 to +6C temperature rise. At +9C temperature, APSIM-ORZYA had greater yield reduction, in fact zero yield) (*There is literature that suggests zero rice yield at a critical temperature threshold, so APSIM may be more correct.*). APSIM-ORZYA indicates lower yield at -3C, whereas CERES-Rice continues to increase yield. Generally rice yield increases with cooler temperature, until Tmin falls below 18C (*so the correct interpretation of this response will depend on what the average Tmin is at this weather site. We also need to verify Tmin effects on grain set in ORYZA, which we think Matthews incorporated 10-15 years ago*).

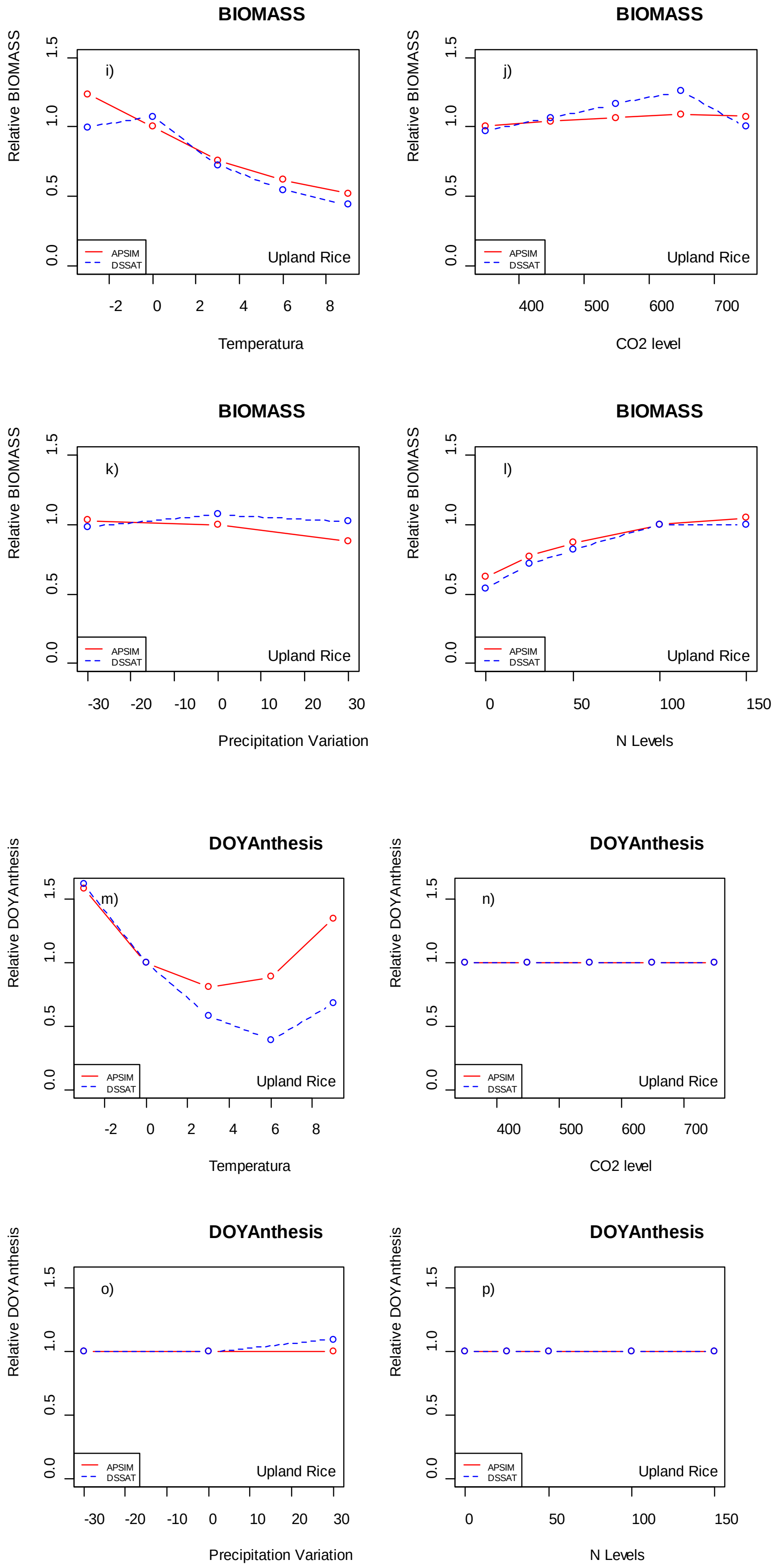
The biomass and LAI responses of both APSIM-ORZYA and CERES-Rice showed decreasing biomass and LAI as temperature increased, although CERES had the highest biomass at the default ambient temperature. Causes for reduction in biomass would be the association with shorter time to anthesis, giving lower LAI, and shorter total life cycle. Together, these factors should also reduce grain yield with rising temperature. It will be important to verify the degree of truth in these responses by comparing model simulations to temperature transect or elevated temperature experiments.

The **CO2 effect** will be discussed briefly, because we are not convinced the simulations were done correctly (APSIM-ORZYA requires some script to designate CO_2 effect, and that may not have been done correctly). The CERES-Rice model gave more than 30% increase in yield with doubled CO_2, and may be too responsive, while yield (and biomass) of APSIM-ORYZA were nearly unresponsive to CO_2 (but was this done correctly?). Prior experience (J. T. Baker & K. J. Boote) indicates that rice yield is increased nearly 30% with doubling of CO_2, and that biomass is almost as responsive as grain yield to CO_2 (*but the simulations did not show that*). LAI response to CO_2 should be fairly small, as shown. As expected, CO_2 had no effect on time to anthesis or maturity in either of the models.

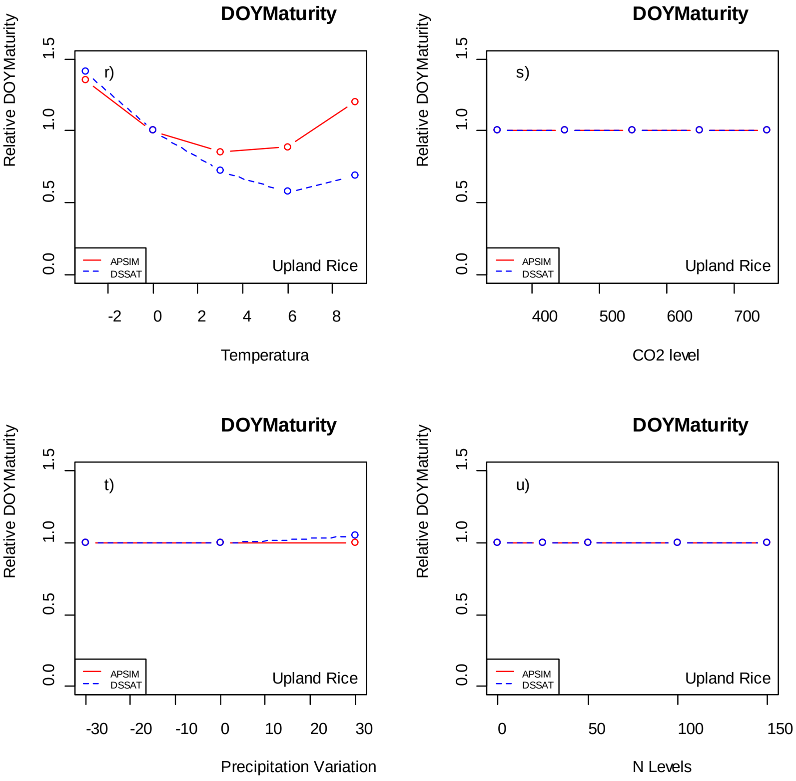
The **rainfall effect** was very small and could indicate that the rainfall was adequate (even if reduced 30%). The effects on yield and LAI with +30% are not understood and the two models go in opposite directions (*so model causes should be explored*). Alternative causes are possible such as differential N leaching versus relief of water deficit. A more though analyses with a full range of water supply should be undertaken to better understand this, so no message should be taken.

The **N effect** was quite similar for both models for yield and biomass. They showed similar response for increasing N from 0 to 100 kg/ha. However, DSSAT did not show response for yield and biomass for N levels higher than 100 kg/ha. For LAI, DSSAT showed a linear response from 0 to 100 kg/ha of N. After that, there was no response for N. APSIM showed a strange behavior for LAI from 50 to 100 kg of N. In ORYZA APSIM, LAI seems to be responding to the strange dynamics of green leaf weight. It was already observed mainly in water stress periods. However, looks like that the same problem arises when there is low nitrogen.





BIOMASS
Relative BIOMASS
i)
j)
k)
l)
APSIM
DSSAT
Upland Rice
Temperatura
CO2 level
Precipitation Variation
N Levels
DOYAnthesis
Relative DOYAnthesis
m)
n)
o)
p)


DOYMaturity
Relative DOYMaturity
r)
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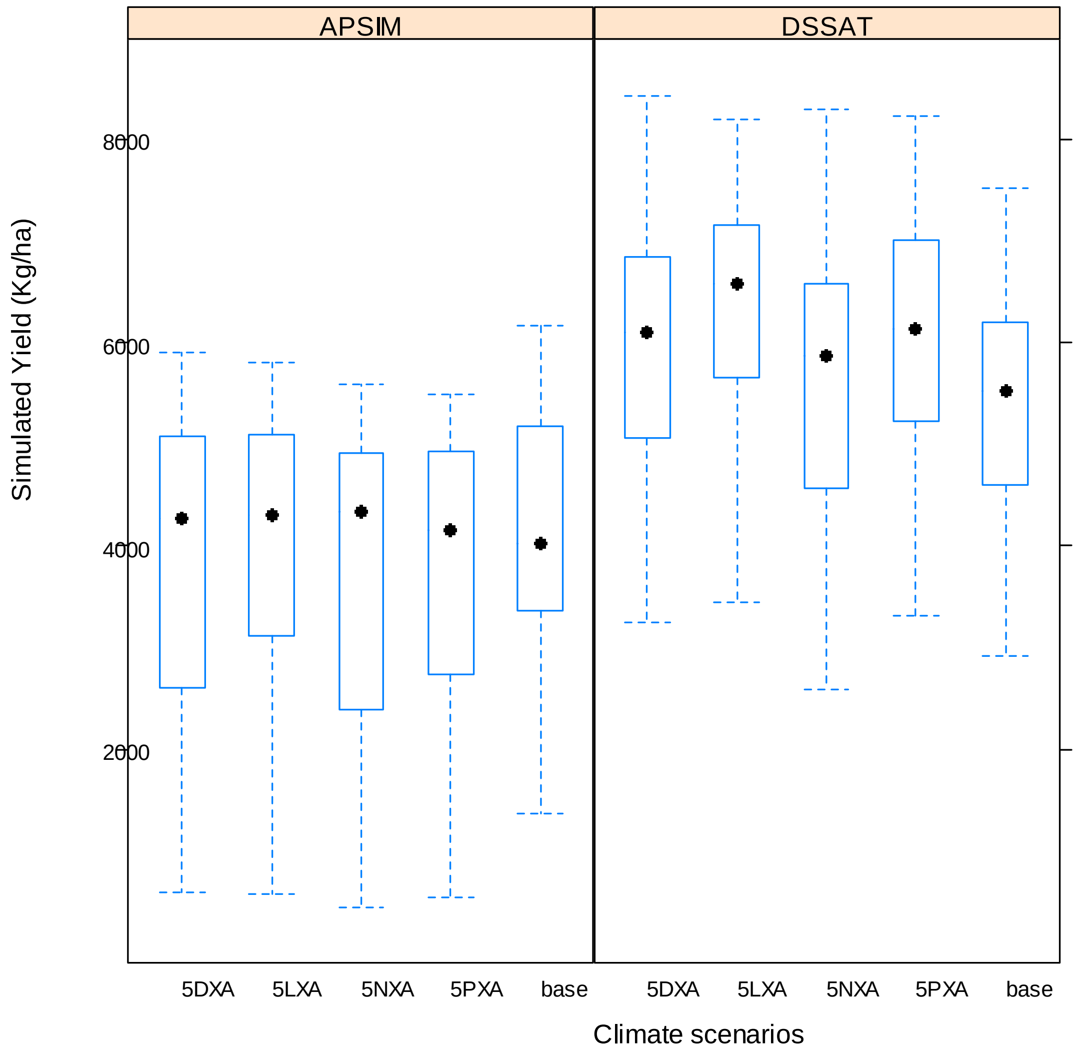
Upland Rice
Temperatura
DOYMaturity
Relative DOYMaturity
s)
APSIM
DSSAT
Upland Rice
CO2 level
DOYMaturity
Relative DOYMaturity
t)
APSIM
DSSAT
Upland Rice
Precipitation Variation
DOYMaturity
Relative DOYMaturity
u)
APSIM
DSSAT
Upland Rice
N Levels

D. Impact of Future Climate Scenarios – Rice Models

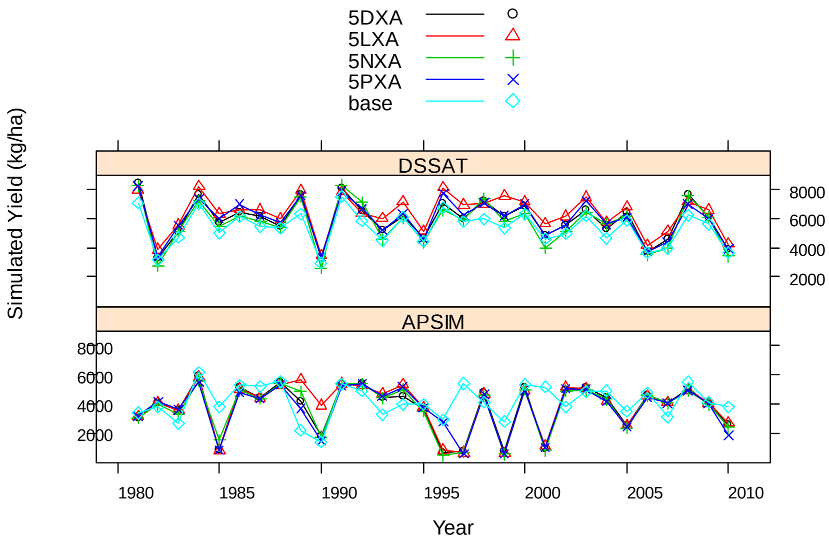
Climate Change Projections

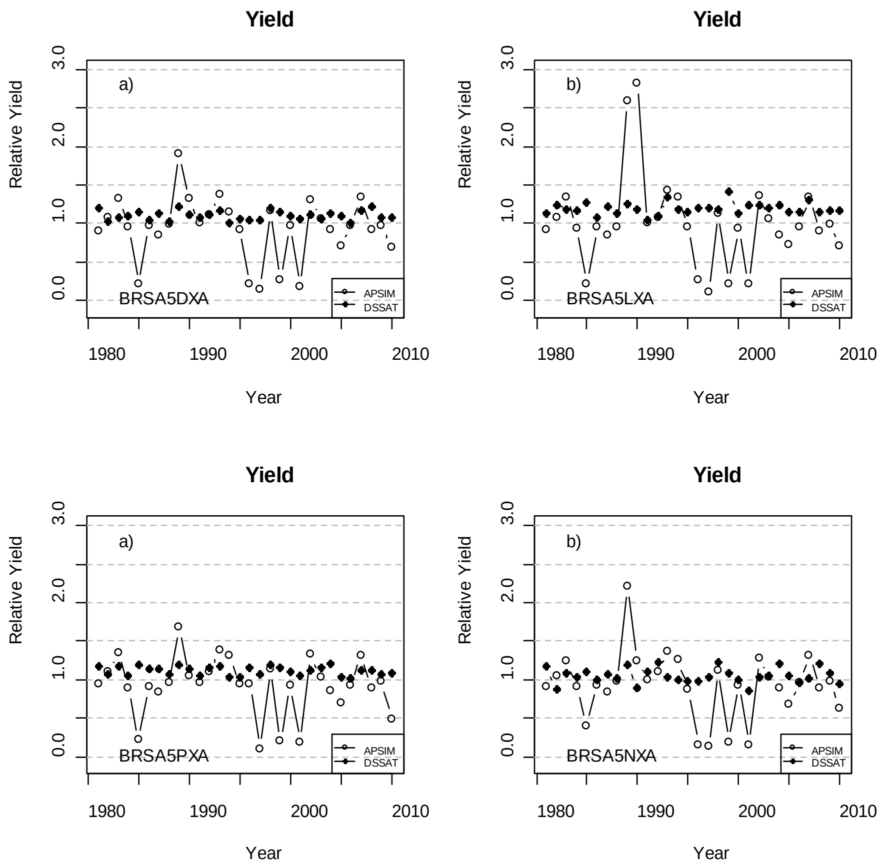
For the single treatment, the APSIM-ORYZA and CERES-Rice models were simulated with 30 seasons of baseline weather (base) and 4 different climate scenarios (BRSA5DAX, BRSA5LAX, BRSA5NAX and BRSA5PAX). The future weather scenarios appeared not to have any significant effects on rice yield that differed from the baseline (*but that depends on how the weather conditions differed from baseline*). The higher yield of DSSAT-CERES-Rice should not be interpreted as important as the model was not calibrated for this site. The simulated yields are presented with box and whisker plots which show the median. In the box-and-whisker plots, the bottom and top edges of the box are located at the 75th percentiles. The center black circle in the box is the media at 50% of yields and the dashed line represents the 25^{th} percentile, the dashed bars at 100% of simulated cases.

The APSIM-ORZYA model showed more cases of near-zero grain yield than DSSAT, and also had a larger range for the 50% quantile. Causes for this should be explored, and are possibly related to temperature as well as rainfall and water deficit since this is a rainfed crop. Yield for APSIM-ORZYA was very low on some “years”, when yield of CERES-Rice was not reduced as much. This was apparently caused by high temperature effects on grain-set in APSIM, as APSIM biomass was not all that much reduced on those weather years. Remember that APSIM had zero yield with +9C sensitivity case example, caused by model functions of temperature effect on grain-set, rather than temperature on photosynthesis or biomass. By contrast, rainfall seemed to be reducing LAI, biomass, and yield of DSSAT-CERES-Rice in some years.

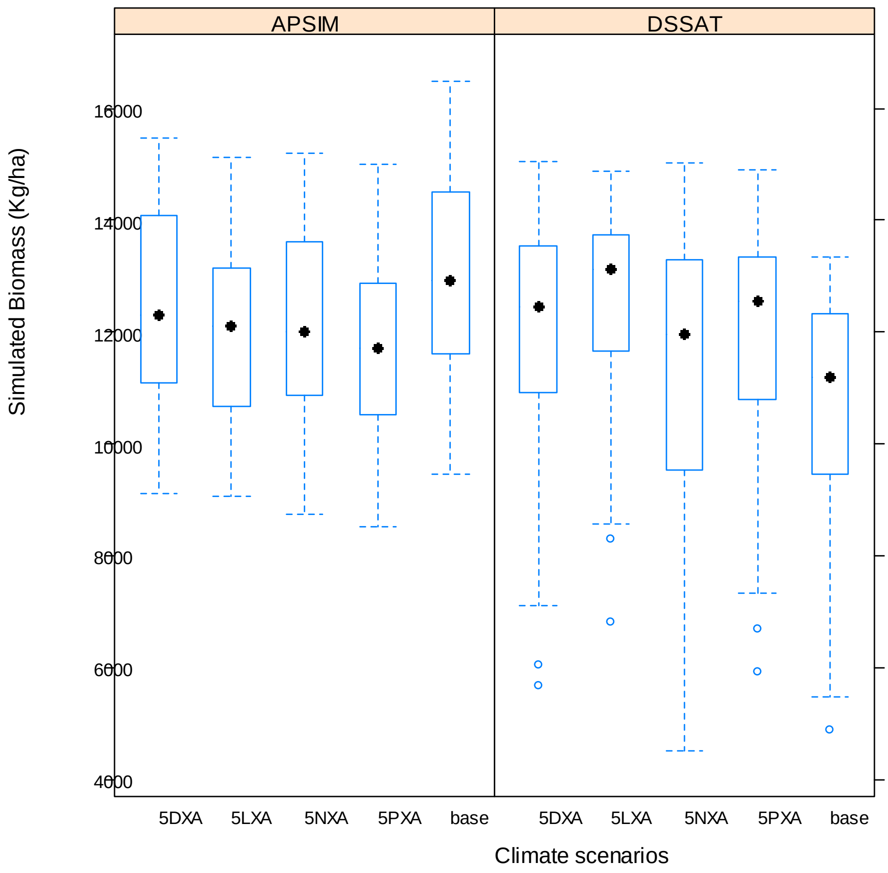


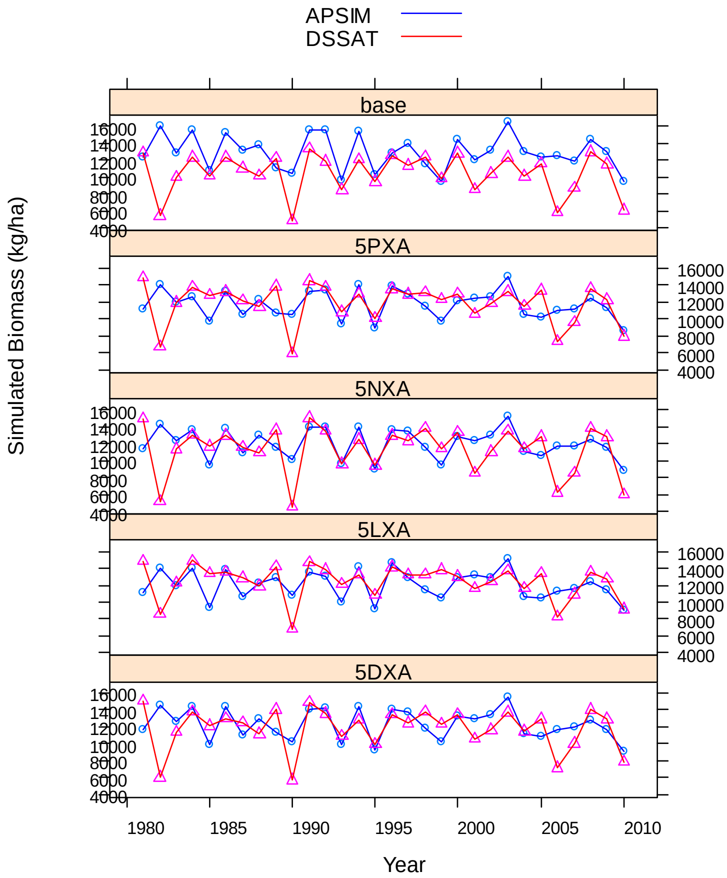
APSIM
DSSAT
Simulated Yield (Kg/ha)
8000
6000
4000
2000
5DXA
5LXA
5NXA
5PXA
base
5DXA
5LXA
5NXA
5PXA
base
Climate scenarios


5DXA
5LXA
5NXA
5PXA
base
DSSAT
APSIM
Simulated Yield (kg/ha)
Year

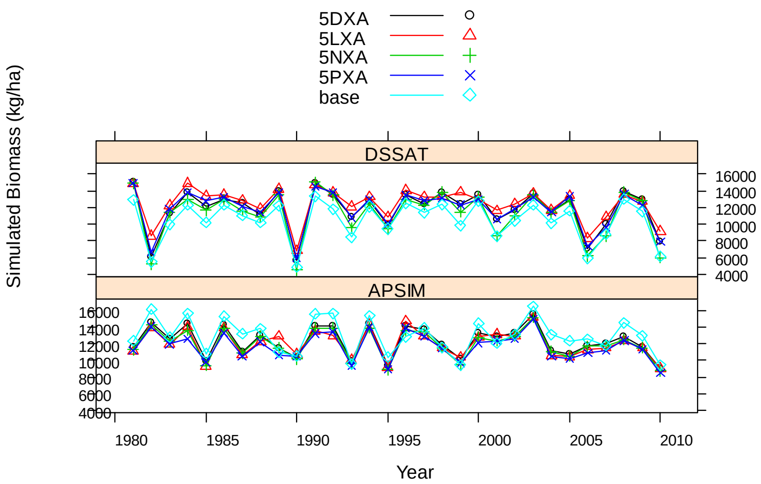

Yield
a)
b)
Relative Yield
BRSA5DXA
BRSA5LXA
BRSA5PXA
BRSA5NXA
APSIM
DSSAT
Year

Biomass at Maturity



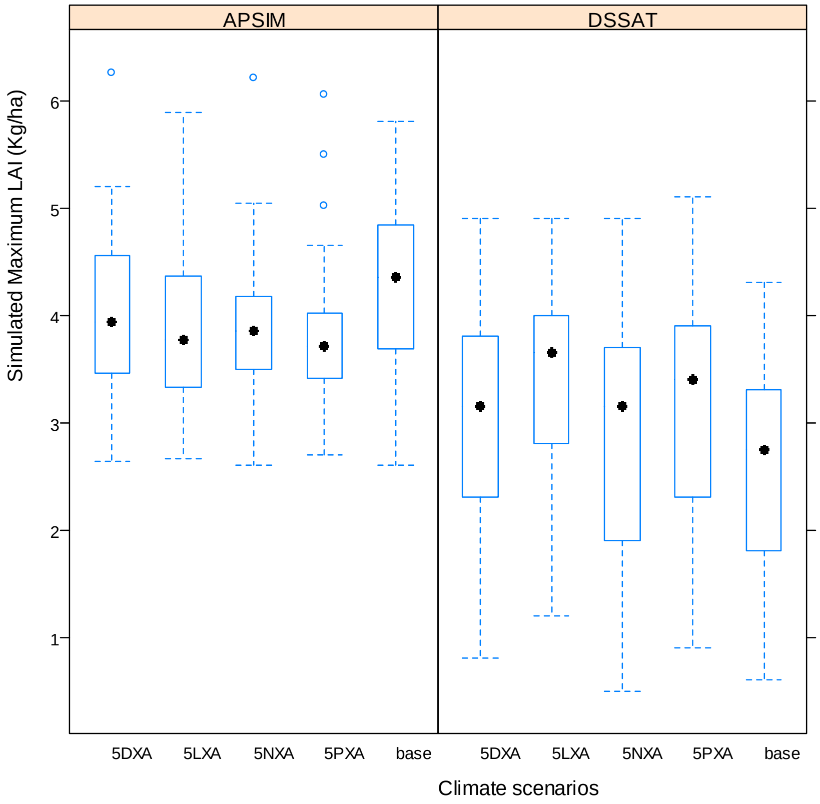


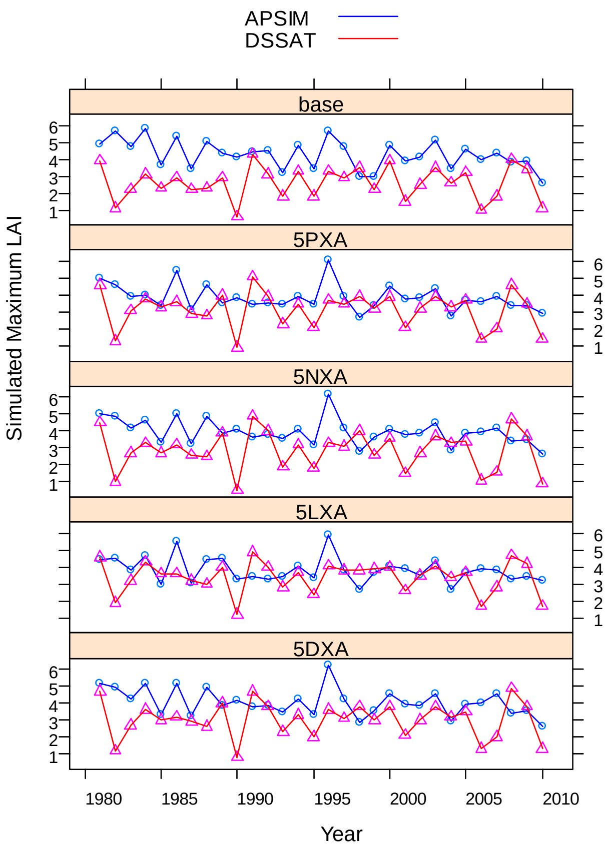
APSIM
DSSAT
base
5PXA
5NXA
5LXA
5DXA
Simulated Biomass (kg/ha)
Year
1980
1985
1990
1995
2000
2005
2010
4000
6000
8000
10000
12000
14000
16000

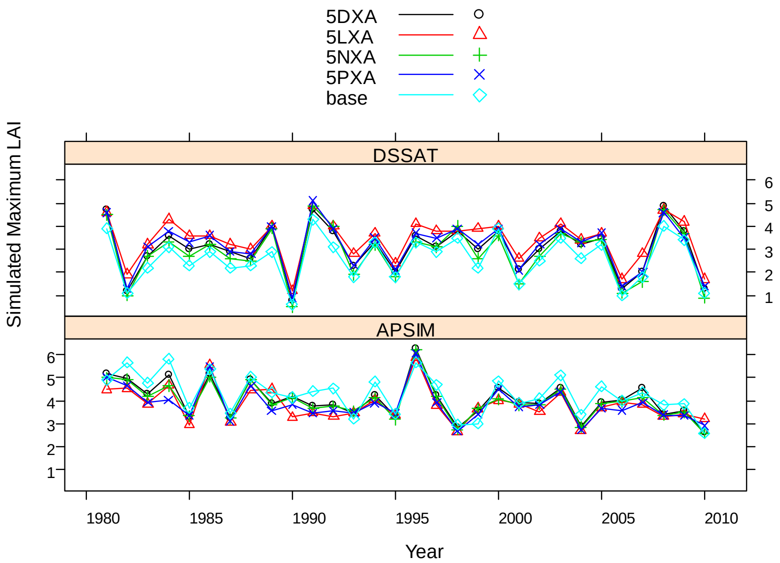


5DXA
5LXA
5NXA
5PXA
base
DSSAT
APSIM
Simulated Biomass (kg/ha)
Year
1980
1985
1990
1995
2000
2005
2010
4000
6000
8000
10000
12000
14000
16000

Maximum LAI


APSIM
DSSAT
Simulated Maximum LAI (Kg/ha)
1
2
3
4
5
6
5DXA
5LXA
5NXA
5PXA
base
5DXA
5LXA
5NXA
5PXA
base
Climate scenarios


APSIM
DSSAT
base
5PXA
5NXA
5LXA
5DXA
Simulated Maximum LAI
1
2
3
4
5
6
1980
1985
1990
1995
2000
2005
2010
Year


5DXA
5LXA
5NXA
5PXA
base
DSSAT
APSIM
Simulated Maximum LAI
1
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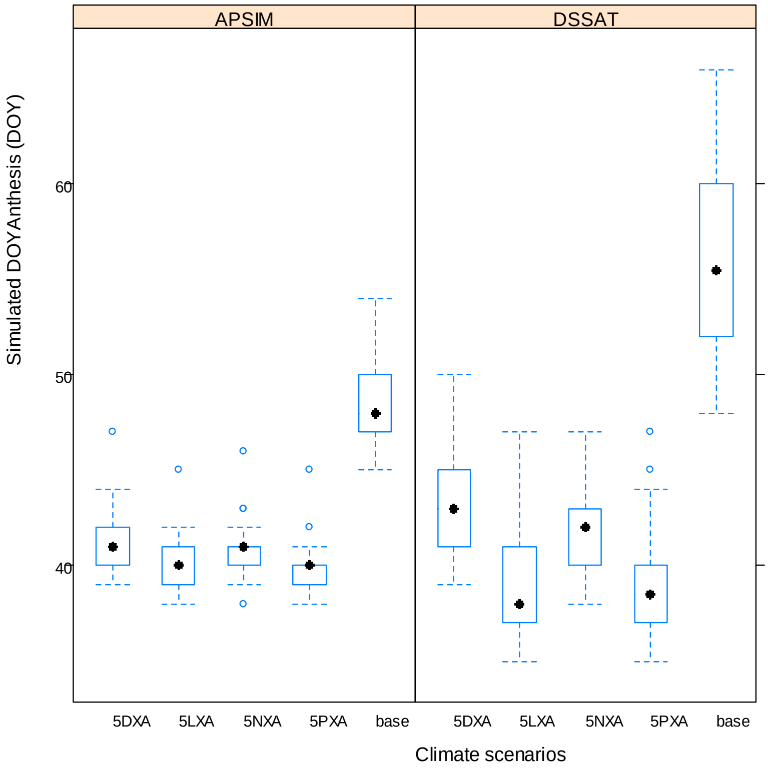
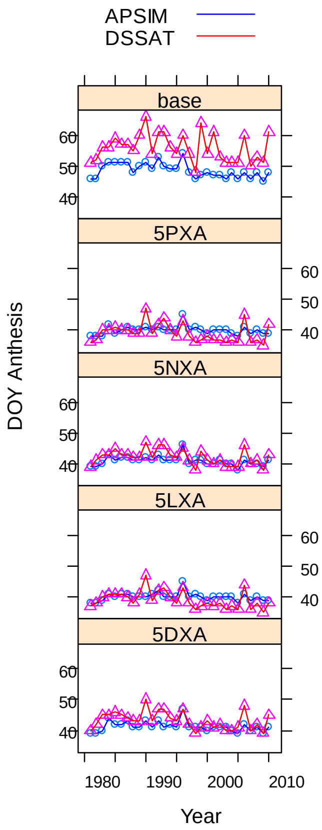
1980
1985
1990
1995
2000
2005
2010
Year

DOY Anthesis

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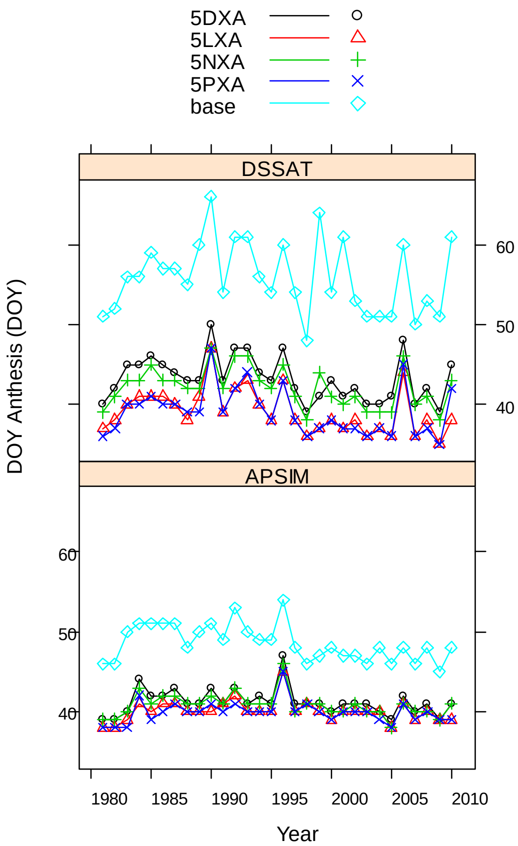
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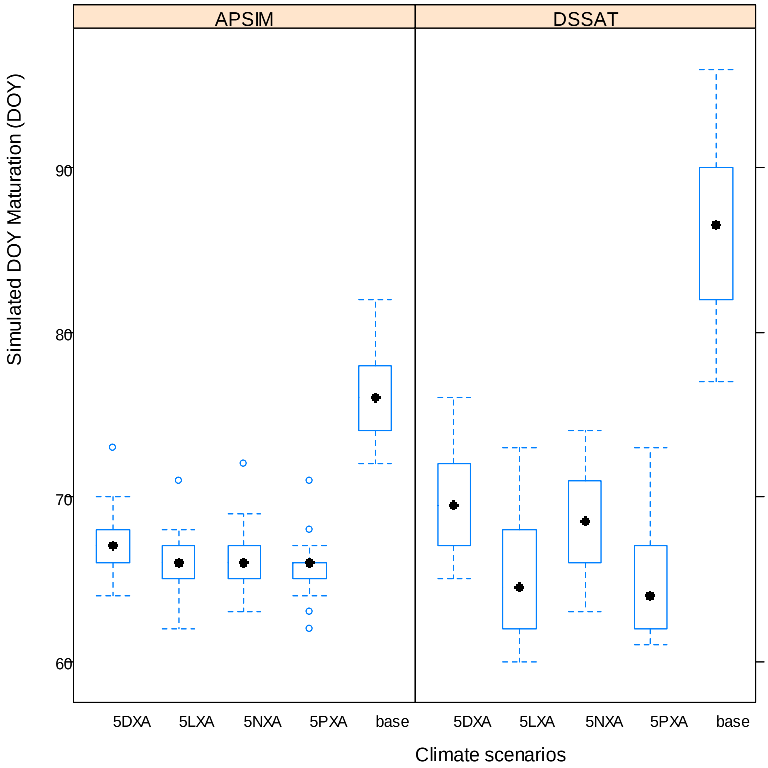

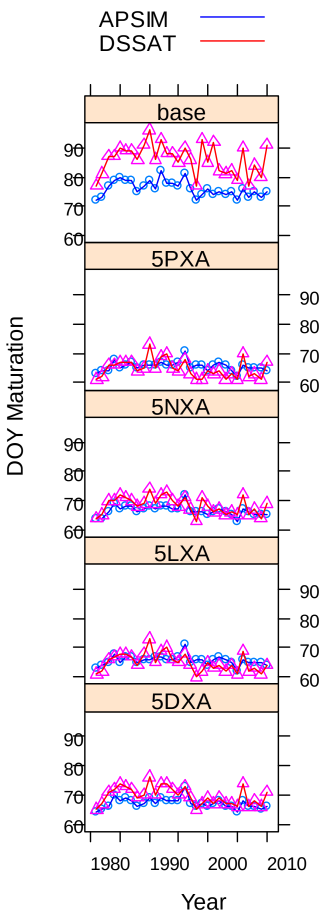

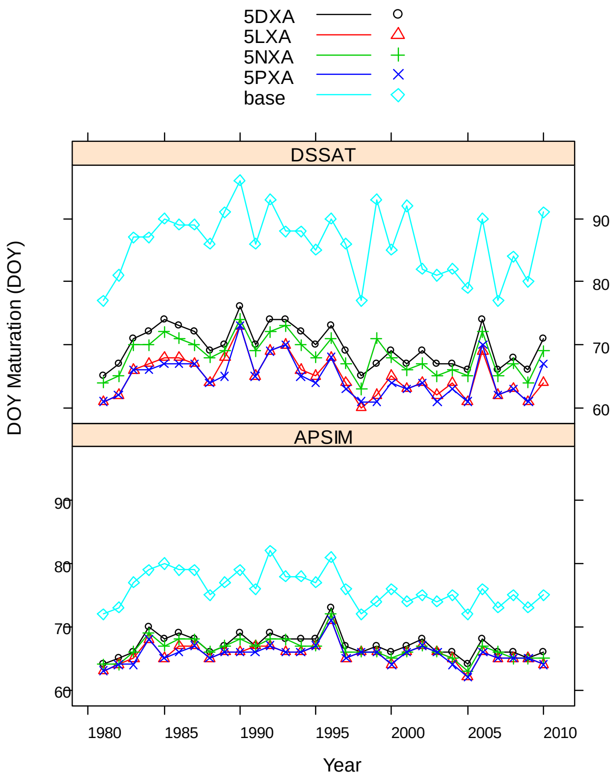
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