WORKSHOP REPORT – Preliminary Draft

Crop Model Analysis of Climate and CO_2 Effects

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Introduction

As part of the Agricultural Sector Assessment within the National Assessment, carried out by the US Global Change Research Program (USGCRP), a workshop was held to initiate a cross-model comparison of several ecosystem and crop growth models that have been used for climate change impact assessment purposes. This report provides information on the design and methodology of the model comparison and discusses some of the preliminary results.

Effects on crop production of changing climate as well as CO_2 have been a major part of previous assessments of climate change impacts (e.g. Adams et al. 1990, Rosenberg et al. 1993, Rosenzweig and Parry 1994), as well as the present National Assessment. Simulation models of crop growth afford one of the only means to perform a structured quantitative analysis that integrates the multiple effects of climate and CO_2, and the interactions with edaphic factors and management, on crop growth and yield.

In the past (and currently), such impact assessments have been done by different groups, using different models and different sets of assumptions. Experience from the climate modeling community, IGBP/GCTE crop modeling networks and the VEMAP ecosystem modeling project (Vemap 1995), suggests that there is much to be gained from performing coordinated modeling exercises to assess the differences and similarities of models used for climate change impact assessment. It can be argued that by using a number of different models, but with a common set of input variables and baseline assumptions, we can obtain a measure of the uncertainty of our predictions. This has become standard practice with the use of general circulation models

(GCM) for climate predictions. It also provides a baseline for interpreting different climate change impacts studies. In other words, if two or more studies give conflicting results is that due to major differences in the models or to different initial conditions and driving variables?

We hosted a two-day workshop to initiate a comparative analysis of results from several well-tested models that have been or are currently being used for predicting changes in crop production as a function of climate and CO_2 changes (See Appendix A). The objective was to derive a common set of model inputs and then to simulate production for some common cropping systems representing major agricultural regions in the US, using each of the models. Because of the limited time and resources for the USGCRP assessment, a comprehensive, comparison of climate change/CO_2 impacts for many different crops and locations across the US was not feasible. Instead, we view the proposed work as providing preliminary results on the range of responses generated by different models for common production systems in major agricultural regions.

Simulation analysis design

Four models were included in the comparison: Century, Ceres (Maize and Wheat), DNDC and EPIC. The Ceres models, EPIC and DNDC utilize a daily time step and both Ceres and EPIC model crop phenology as a function of accumulated heat units (i.e. degree days). The Century model includes a simple crop model that runs on a monthly time step and does not directly model crop phenology, utilizing a harvest index approach to partition the above ground biomass. Century, DNDC and EPIC models include relatively detailed soil biogeochemical processes for carbon and nitrogen and all four models include temperature and water balance submodels. The primary focus of the Ceres models is simulation of crop yield, while the main focus of Century and DNDC is simulation of carbon and nitrogen dynamics in the ecosystem. The EPIC model was originally designed primarily to look at soil erosion and crop yield relationships. All the models have been used to varying extent for climate change impact assessments.

Seven locations, located in the major field crop production regions in the US were chosen for the model comparisons. The locations were: Columbus, OH (Eastern Corn Belt), Fargo, ND (N. Great Plains – Spring wheat belt), Fresno, CA (Central valley), Montgomery, AL (Southeast), North Platte, NE (Central Great Plains – Winter wheat belt), Spokane, WA (Pacific NW Wheat belt) and Topeka, KS (Western Corn Belt).

Climate conditions included current (1970-1990) and future climate (2080-2100) scenarios, from a subset of those used for the US Agriculture Assessment. The output from both the Canadian Climate Center (CCC) and Hadley Center (HC) models were used. The two climate scenarios were run using both current (350 ppm) and projected (660 ppm) CO_2 concentrations; current climate was simulated using only current CO_2 levels.

For ease of interpretation, a single soil type and profile description (a medium silt loam soil, IBSNAT # IB00000005) was used for each site by all the models.

Because each of the models differ in approach, level of detail and input requirements (with respect to crop characteristics), a common data set was compiled, sufficient to initialize each of the models. The objective was to have a single consistent source of input data so that potential differences in model results due to varying assumptions about model initialization made by each investigator would be minimized. The data set included specified degree days to anthesis and maturity, average and maximum yield (under current climate) and average harvest index.

Simulations were run for two crops, maize and wheat (spring wheat was simulated at Fargo, ND; winter wheat at all other sites), under both non-irrigated and irrigated conditions, for two levels of N fertilizer input. Irrigation was simulated assuming that when water contents in the root zone drops to 50% of the water holding capacity (WHC), water would be added to reach 100% of WHC. The two fertilizer levels were 100 and 200 kg N ha yr^{-1} for maize and 40 and 80 kg N ha yr^{-1} for wheat, added at planting, as NH_4NO_3. Conventional tillage treatments were specified for each site. An example of the model input information is given in Appendix B.

Results

A large number of variables are being analyzed and compared to get a picture of how, and why, the models differ in their response to climate, CO_2 change and management across the sites. These output variables include crop yield, net primary production, transpiration and water balance and soil C and N levels. Many of these responses remain to be analyzed and only preliminary results for model simulations of grain yield under the various climate scenarios for six of the sites (excluding North Platte, NE) are shown. Since DNDC does not include a CO_2 response function, the comparisons shown here are all for current (350 ppm) CO_2 levels, with and without climate change.

For maize, all the models predicted roughly similar site-to-site differences in yield under current conditions (Figs 1a,b), with the lowest yields in low precipitation areas (Fresno, CA and Spokane, WA) and the highest yields in the Corn Belt locations (Columbus, OH and Topeka, KS). The two models that showed the greatest similarity in outputs were the EPIC and Ceres-Maize models – in most instances, yield differences between the two were less than 10%. This was not unexpected since these two models are the most similar in approach to modeling crop growth and development. The DNDC model usually predicted the lowest yields, in some cases showing up to 50% less yield than the other models. At the high fertilizer level, Century results were similar to those from Ceres-maize and EPIC at most sites, but with low fertilizer addition, Century predicted greater yield reductions than these other two models. Predictions of irrigated yields at the high N addition were quite similar across models and sites, for both base and climate change scenarios. With the low fertilization rate (and irrigated), both Century and DNDC predicted substantially lower yields compared with Ceres-maize and EPIC, which again show little response to the differences in N input.

The pattern of yield response to the climate change scenarios varied by model and site. With the climate scenario from the Canadian Climate Center model (CCC), yields tended to decrease at most sites for all the models (Fig 2a,b). EPIC (and to a lesser extent Ceres-maize) predicted large *relative* increases at Fresno and Spokane – however, this is somewhat misleading since yields under the base climate were predicted to be very low, less than 0.5 tonnes ha^{-1}, by EPIC. For the Corn Belt sites (Columbus and Topeka) the Century and DNDC models predicted increased yield under climate change, while EPIC and Ceres predicted decreases. The predicted yield decreases for these two models are likely due to a shortened grain-filling period as a result of higher temperatures, and thus an decrease in harvest index – processes which are not as well represented in Century and DNDC. Using output from the Hadley center model, which predicts less temperature increase and a larger precipitation increase than does the CCC, all the models tended towards constant or increased yields for dryland corn. For irrigated corn, yields tended to be reduced (relative to the base climate) for most of the sites, for both the CCC and HC simulations.

Wheat yields were more similar across sites than for maize (Fig. 3a,b). There was less agreement in yield levels between Ceres-wheat and EPIC, than was the case for maize, with EPIC predicting generally higher yields than Ceres. The Century model predicted the highest of any of the models at three of the sites for all of the climate scenarios. The effects of climate change on wheat yields were similar for both the Hadley Center and Canadian Climate Change model (Fig. 4a,b). Most of the models agreed on increased wheat yields under climate change for the Ohio, California and Washington sites, and decreased or unchanged yields at other sites.

Further analysis of the responses of these models, and where and why they agree or disagree in simulating crop responses to changes in climate and CO2 are ongoing. Further insight will be gained from examining outputs for other associated processes such as transpiration and nutrient cycling. However, our preliminary results suggest that regional patterns in crop productivity are represented consistently by all the models, in most cases. Climate change responses vary somewhat more between models but the direction and magnitude of yield changes were more similar than dissimilar between models.

Literature cited

Adams, R., C. Rosenzweig, J. Ritchie, R. Peart, J. Glyer, B. McCarl, B. Curry and J. Jones. 1990. Global climate change and US agriculture. Nature 345:219-224.

Rosenberg, N.J. (ed.) 1993. Towards and Integrated Assessment of Climate Change: The MINK study. Kluwer Academic Publ., 173 p.

Rosenzweig, C. and M.L. Parry. 1994. Potential impact of climate change on world food supply. Nature 367:133-138.

VEMAP. 1995. Vegetation/Ecosystem modeling and analysis project (VEMAP): Comparing biogeography and biogeochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. Global Biogeochemical cycles 9:407-437.

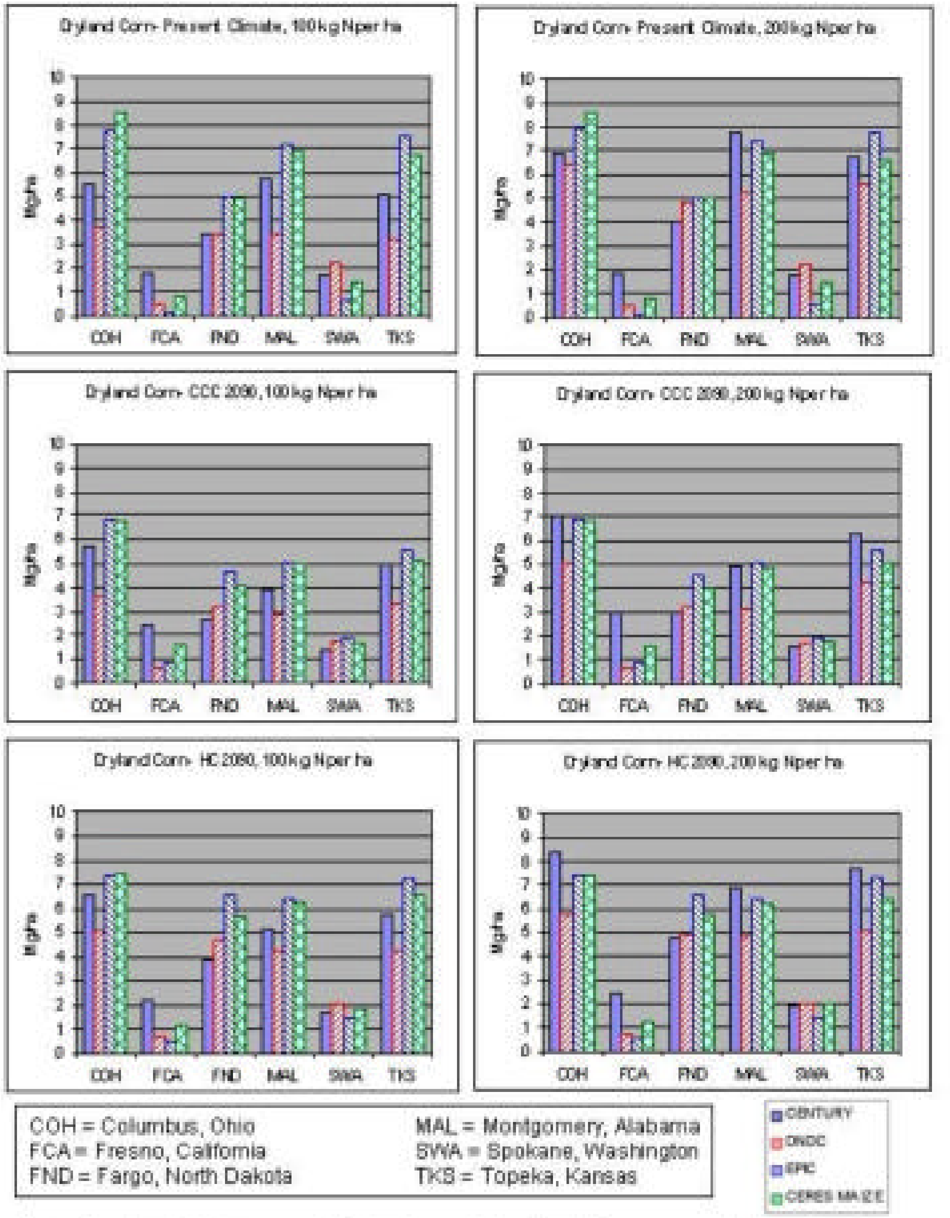
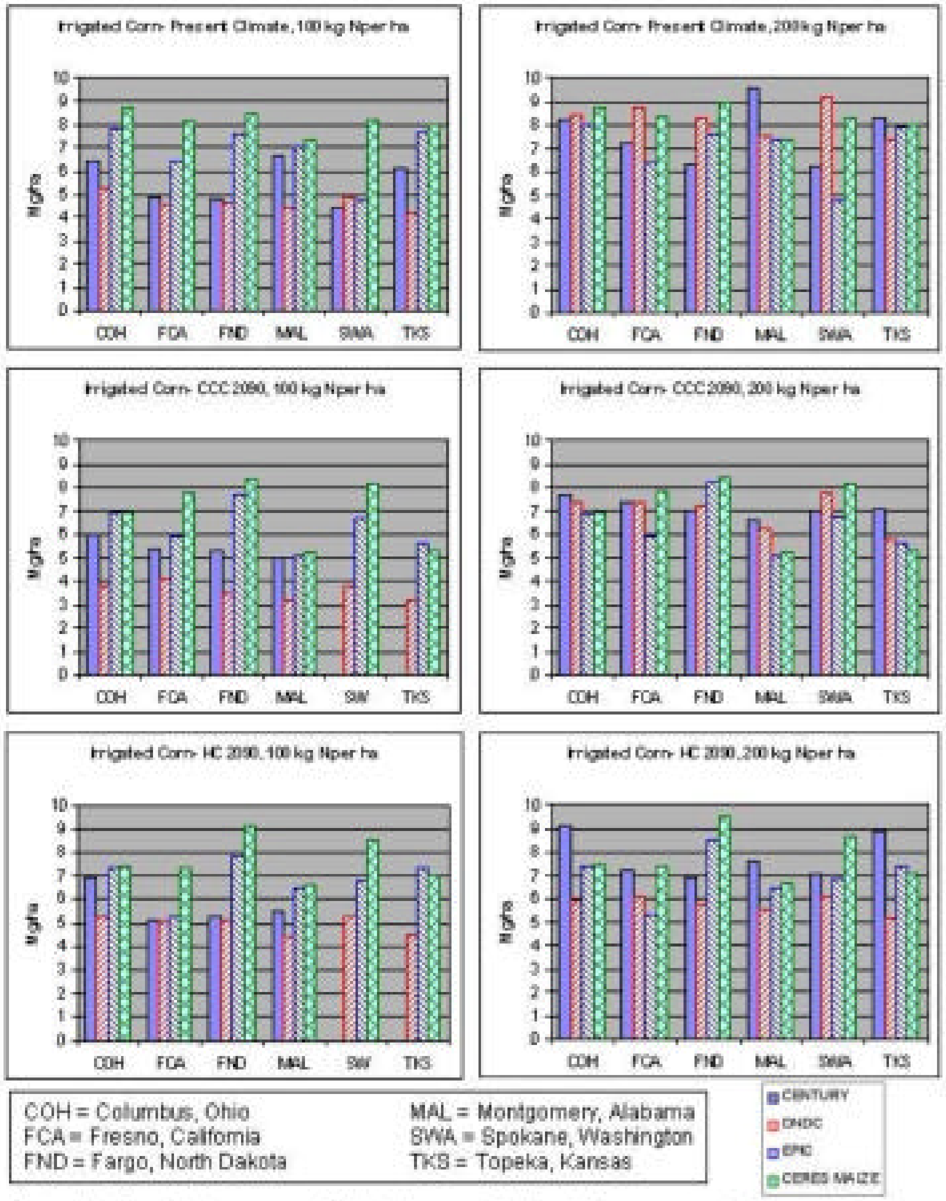
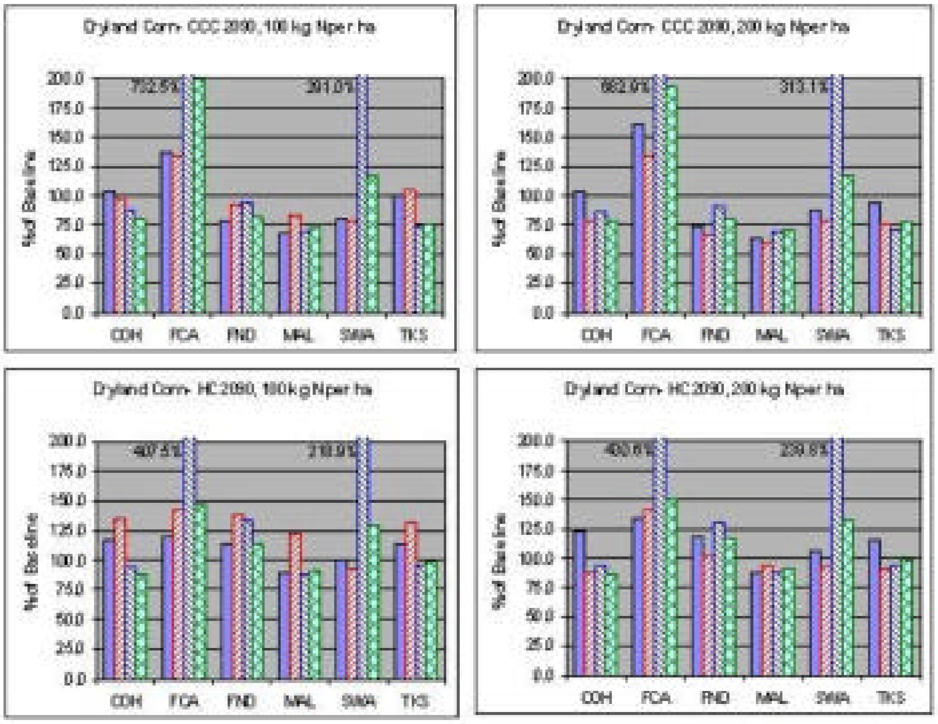


Figure 1a. Predicted response of dryland corn at six sites to four crop production and soil carbon models with two fertilization regimes, showing response to present climate and two climate change scenarios (CCC-Canadian Climate Change and HC- Hadley Center) under 2x CO_2 levels (660 ppm).



COH = Columbus, Ohio
FCA = Fresno, California
FND = Fargo, North Dakota
MAL = Montgomery, Alabama
SWA = Spokane, Washington
TKS = Topeka, Kansas

Figure 1b. Predicted response of irrigated corn at six sites to four crop production and soil carbon models with two fertilization regimes, showing response to present climate and two climate change scenarios (CCC-Canadian Climate Change and HC- Hadley Center) under 2x CO_2 levels (660 ppm).



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- 🟦 CENTURY
- 🟥 DNDC
- ▨ EPIC
- 🟩 CERES MAIZE

Figure 2a. Predicted response of dryland corn at six sites to four crop production and soil carbon models with two fertilization regimes, shown as percent of present climate baseline models. Response is shown two climate change scenarios (CCC-Canadian Climate Change and HC- Hadley Center) under 2x CO_2 levels (660 ppm).

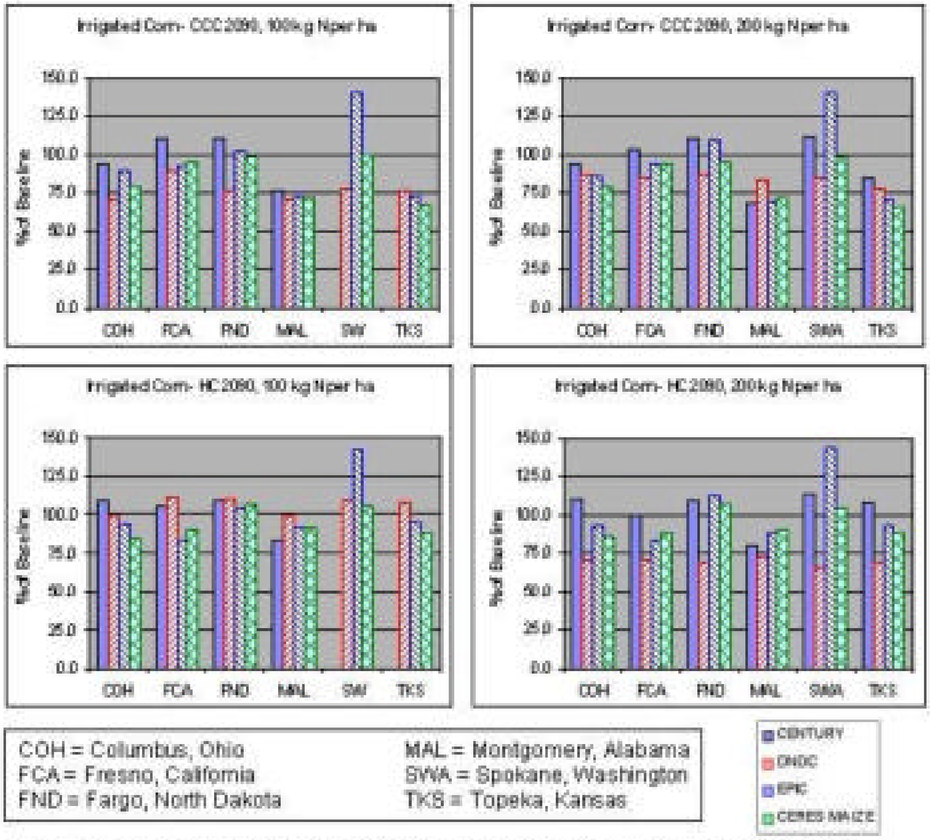

Figure 2b: Predicted response of irrigated corn at six sites to four crop production and soil carbon models with two fertilization regimes, shown as percent of present climate baseline models. Response is shown two climate change scenarios (CCC-Canadian Climate Change and HC- Hadley Center) under 2x CO_2 levels (660 ppm).

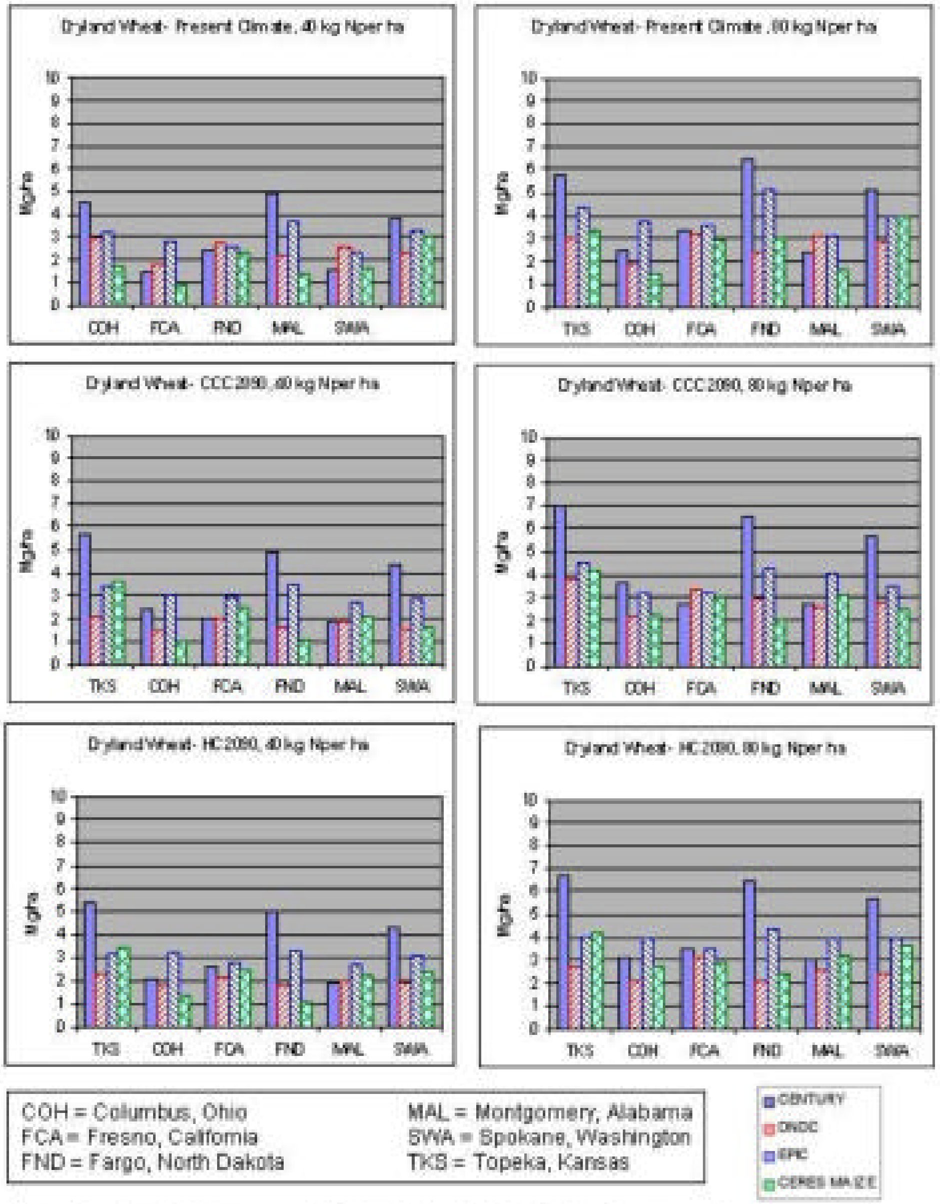

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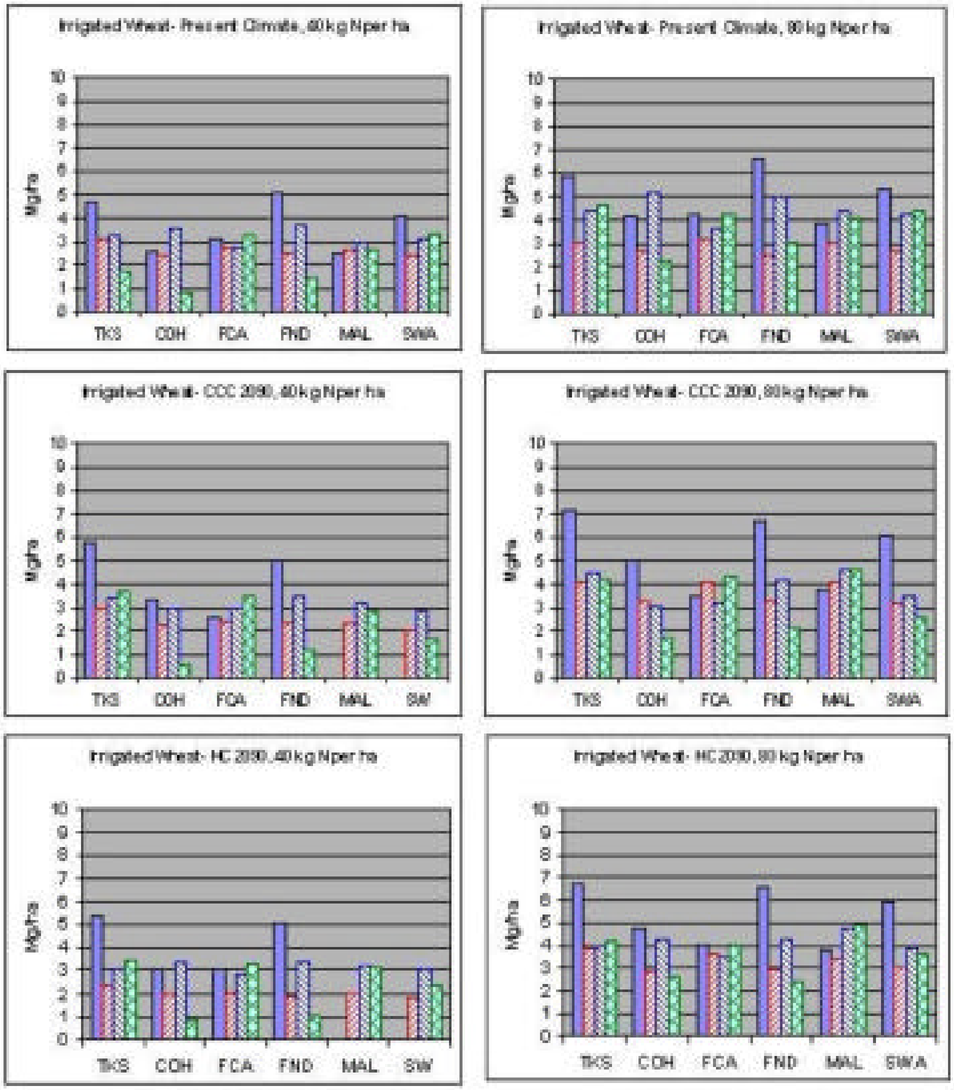
Figure 3a. Predicted response of dryland wheat at six sites to four crop production and soil carbon models with two fertilization regimes, showing response to present climate and two climate change scenarios (CCC-Canadian Climate Change and HC- Hadley Center) under 2x CO_2 levels (660 ppm).



Irrigated Wheat- Present Climate, 40 kg N per ha

Irrigated Wheat- Present Climate, 80 kg N per ha

Irrigated Wheat- CCC 2090, 40 kg N per ha

Irrigated Wheat- CCC 2090, 80 kg N per ha

Irrigated Wheat- HC 2090, 40 kg N per ha

Irrigated Wheat- HC 2090, 80 kg N per ha

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Figure 3b. Predicted response of irrigated wheat at six sites to four crop production and soil carbon models with two fertilization regimes, showing response to present climate and two climate change scenarios (CCC-Canadian Climate Change and HC- Hadley Center) under 2x CO_2 levels (660 ppm).

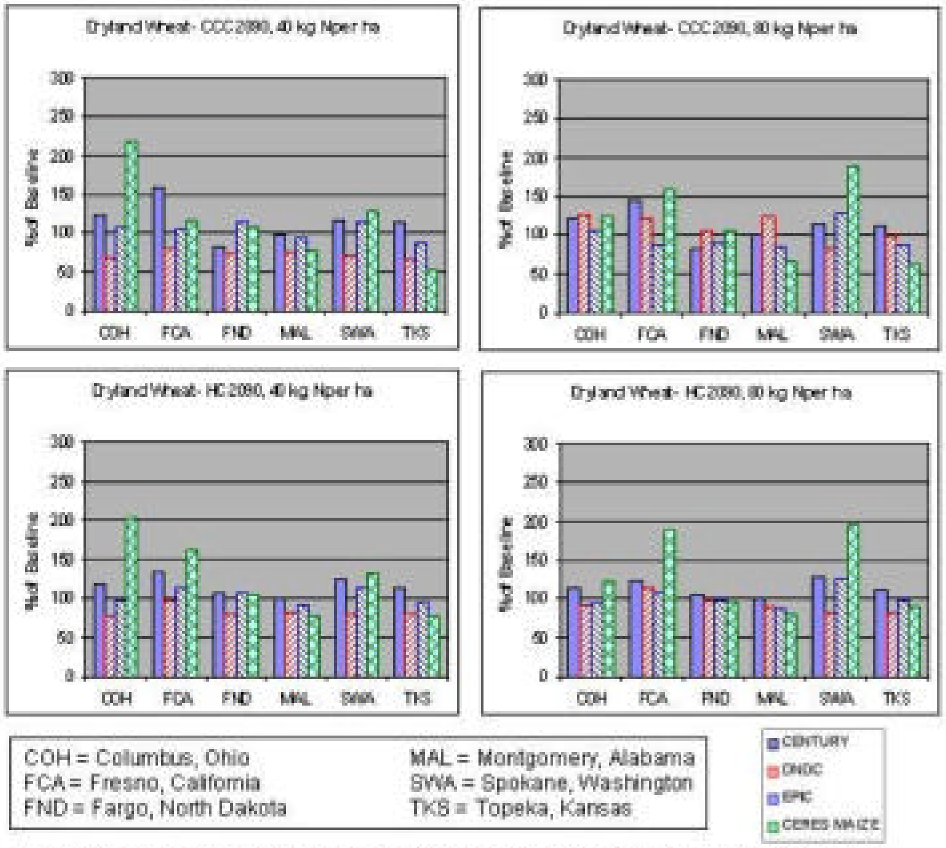

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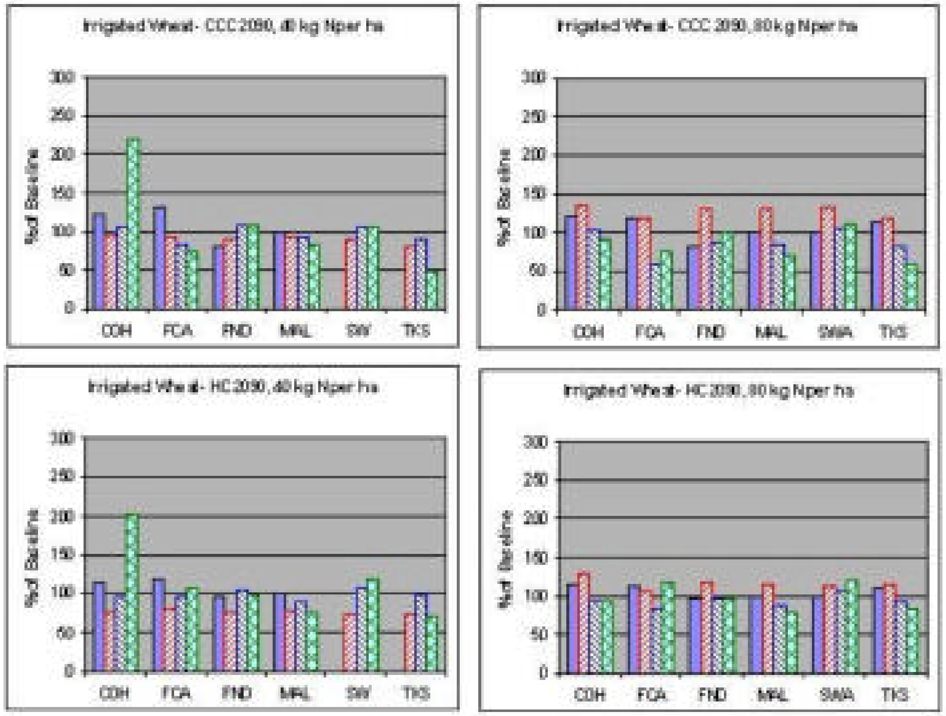
Figure 4a. Predicted response of dryland wheat at six sites to four crop production and soil carbon models with two fertilization regimes, shown as percent of present climate baseline models. Response is shown two climate change scenarios (CCC-Canadian Climate Change and HC- Hadley Center) under 2x CO_2 levels (660 ppm).



COH = Columbus, Ohio
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Figure 4b: Predicted response of irrigated wheat at six sites to four crop production and soil carbon models with two fertilization regimes, shown as percent of present climate baseline models. Response is shown two climate change scenarios (CCC-Canadian Climate Change and HC- Hadley Center) under 2x CO_2 levels (660 ppm).

APPENDIX A

Agenda for Crop Model Analysis of Climate and CO_2 Effects
Colorado State University
Natural Resource Ecology Laboratory
NREL Conference Room B215
September 1-3, 1999

Wednesday Sept 1, 1999

Wednesday Morning

8:45	Meet in Helmshire Lobby
9:00	Welcome to NREL: Jill Lackett, Dennis Ojima, Keith Paustian Logistics Agenda Review Introductions
9:30	Presentations by Modeling Groups: Short 20 minutes descriptions of key model features and preliminary findings relative to climate and CO2 scenarios used for the intercomparisons.
	Francesco Tubiello: NASA-Goddard Institute for Space Studies
	Robbie Brown and Cesar Izaurralde: Pacific Northwest National Laboratory
	Shrikant Jagtap: University of Florida, Agricultural & Biological Engineering
10:30	Break
10:45	Resume Presentations
	Robin Kelly: Century, NREL
	Changsheng Li: Complex Systems Research Center
	Hanquin Tian: The Ecosystems Center
	Elena Tsvetsinskaya: ESIG, NCAR
12:15	Lunch:

Wednesday Afternoon

1:15	Group Discussion: Determine Use of Standard Input/Management Protocols
3:15	Break
3:45	Group Discussion: Refine Outline of Intercomparison Paper
5:00	Wrap-up: Review of Progress to Date
6:30	Dinner at Sri Thai

Thursday, Sept 2, 1999

Thursday Morning

9:00 Group Discussion: Paper Outline Continued: Develop Figures and Tables Needed

Small Groups: Work on Simulation results

11:30 Group Discussion: Status of Progress

12:30 Lunch

Thursday Afternoon

1:30 Small Groups: Work on Simulation results (continued)

4:00 Group Discussion: Status of Progress

5:00 Close for the Day

6:30 Dinner

Friday, Sept 3, 1999

Friday Morning

9:00 Group Discussion: Model Results and Interpretation of Climate and CO_2 Effects on Crop Systems; How Do Different Models Exhibit Sensitivity to Climate and CO2.

Small Groups: Work on Figures and Tables

12:30 Lunch

Friday Afternoon

1:30 Group Discussion: Where Are We Now??? What Are the Next Steps? What Is the Timeline?

4:00 Wrap-up

Appendix B

Model input information for US Agriculture assessment – comparison of models for impact assessment.

SITE: North Platte, NE
ROTATION: Winter Wheat

SOIL DESCRIPTION AND INITIAL CONDITIONS
texture designation medium silt loam
IBSNAT# IB00000005

depth (cm)	% sand	% silt	%clay	bulk density	H_2O – LL	H_2O – DUL	H_2O – SAT	% C	% N	pH(H_2O)
0-5	30	60	10	1.37	0.106	0.262	0.362	1.16	0.12	6.5
5-15	30	60	10	1.37	0.106	0.262	0.362	1.16	0.12	6.5
15-30	30	60	10	1.37	0.106	0.262	0.362	1.00	0.10	6.5
30-45	30	60	10	1.37	0.107	0.262	0.362	0.96	0.10	6.5
45-60	30	60	10	1.37	0.107	0.262	0.362	0.96	0.10	6.5
60-90	30	60	10	1.38	0.108	0.261	0.361	0.72	0.07	6.5
90-120	30	60	10	1.38	0.11	0.26	0.36	0.43	0.04	6.5
120-150	30	60	10	1.39	0.111	0.259	0.359	0.20	0.02	6.5

MANAGEMENT SCHEDULING

Planting
Date: 14 September
Pop (#m^2): 180
Row Spacing (cm): 18
Plant Depth (cm): 4
Harvesting
Date: At maturity
Method: Grain only
Tillage
Date: 1 month prior to planting
Methods/Implements: Sweep/field cultivator/planting drill
Max Depth: 7 cm
N Fertilization

Treatment	Date	Amount	Type
1) Low	at planting	40 kg N/ha	NH_4NO_3
2) High	at planting	80 kg N/ha	NH_4NO_3

Irrigation
Treatment
1) None
2) Automatic – add water to reach 100% of soil water holding capacity when WHC in the root zone drops to <50%