Effect of climate change on field crop production and greenhouse gas emissions in California's Central Valley

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Abstract
Predictions of climate change under various emission scenarios is highly uncertain but is expected to affect agricultural crop production in the 21st century. However, we know very little about future changes in specific cropping systems under climate change in California's Central Valley. Here, we used DAYCENT to simulate changes in yield and fluxes of greenhouse gases under A2 (medium-high) and B1 (low) emission scenarios. In total, 18 climate change predictions for the two scenarios were considered by applying different climate models and downscaling methods. The following crops were selected: alfalfa (hay), cotton, maize, winter wheat, tomato, rice, and sunflower. The simulations suggest that future climate change under the different emission scenarios will lead to a broad range of impacts on crop yields. By 2097, yields under A2 decreased in comparison to the 2009 baseline in the following order: cotton (29%) > sunflower (27%) > wheat (17%) > rice (12%) > tomato (9%) > maize (8%).Yields were between 5% (alfalfa) and 21% (cotton) lower under A2 compared to B1. Under A2, soil carbon (C) storage tended to decrease under climate change due to a decrease in C inputs to the soil and an increase in soil C decomposition. However, differences in nitrous oxide (N_2O) flux between A2 and B1 were not clear.

Key Words
Ecosystem modeling, Mediterranean climate, global warming potential, soil organic carbon.

Introduction

Agricultural crop production is fully expected to be impacted by climate change, but our understanding of climate change and its impacts on California cropping systems in the 21st century is limited. Lobell *et al.* (2006) investigated the impact of climate change on perennial crops (e.g., wine grapes), which are high-value commodities in California. However, long-term climate change effects have not been fully tested for major California annual crops and alfalfa (hay). Therefore, it is pertinent to further evaluate potential changes in the production of these systems in California's Central Valley under a changing climate. A detailed analysis of baseline climate change impacts on cropping systems should precede the development of adaptation scenarios based on alternative management practices under various climate change predictions.

Complex ecosystem models, such as DAYCENT, represents an excellent tool for predicting yields as it accounts for a range of interacting conditions in climate, soil, and management. These process-based models can effectively integrate crop growth, nutrient dynamics, hydrology, management, and climate for diverse cropping systems and therefore provide a best-estimate of climate change effects on crop yields and greenhouse gas emissions from these systems. Future climate change under A2 and B1 emission scenarios from the IPCC Fourth Assessment Report were evaluated extensively (Cayan *et al.* 2008). Temperatures are predicted to increase from 1.5°C under B1 to 6°C under A2 by the end of the century relative to 1960–1990. Specifically for California, more warming is expected in summer than winter with increasing frequency of heat waves. Annual precipitation shows relatively small changes (less than 10%) in the same period.

The objective of this study was (1) to project long-term field crop yields and greenhouse gas emissions in California's Central Valley under the A2 and B1 emission scenarios using the DAYCENT model, and (2) to quantify uncertainties in simulations derived from uncertainties around predicted changes in climate.

Methods

Data acquisition

Climate data under the A2 and B1 emission scenarios were obtained from the Climate Research Division of Scripps Institution of Oceanography, at the University of California, San Diego. Six GCMs were applied for the two emissions scenarios: (1) CNRM-CM3, (2) GFDL-CM2.1, (3) CCSR-MIROC3.2 (medium resolution), (4) ECHAM5/MPI-OM, (5) NCAR-CCSM3.0, and (6) NCAR-PCM1 (Randall *et al.* 2007). Each climate change scenario was simulated over the time span 1950–2099. The climate data were downscaled using a constructed analogues (analog) method and a bias correction and spatial downscaling (bcsd) method. We obtained soil data for all climate grids in California from the Soil Survey Geographic Database of the Natural Resources Conservation Service. The land use survey data for agriculture were obtained from the California Department of Water Resources. The statewide historical data were obtained from the United States Department of Agriculture - National Agricultural Statistics Service (NASS). Crop phenology and growing patterns were calibrated using historical crop yield data from NASS. Biomass C and N data, C allocation to shoots and roots, and N dynamics data were also calibrated from various literature sources. Details on conventional management practices in the region (e.g., planting, fertilization, irrigation, weed control, and harvesting) were obtained from the Agronomy Research and Information Center and Cost and Return Studies (2000–2005) available through the University of California Cooperative Extension.

Modeling

We modeled approximately 50% of California's Central Valley, currently covering 1.4×10^6 ha. After initializing the size of soil organic matter pools in the model (years 0-1949), crop rotations for years 1950–2099 were randomly selected based on the acreages of the selected crops. We simulated the increasing use of fertilizer as indicated in the USDA historical records, and also considered different varieties for each period (e.g., low yielding vs. high yielding maize varieties). We did not consider any future adaptations for management practices (e.g., adjustment of crop variety and planting dates, alternative cultivation methods, timing and amount of fertilizer and irrigation use, etc.) in response to changes in climate for years 2007–2099.

Data analysis

For a combination of crops, climate models, and downscaling methods, annual average yields and greenhouse gas fluxes were calculated from 1950 to 2099, weighted by the acreage of the crop planted in each grid. A five-year moving average was then computed to consider trends in yield and greenhouse gas variance.

Results and discussion

The model simulated the observed yields relatively well for all crops in the period 1953 to 2004, although yield variance for some crops (i.e., cotton and sunflower) were not very well reproduced. In general, the effects of climate change on changes in yield (relative to the 2009 average yields) were not obvious in the period 2010 to 2050. However, in the next period (2051–2097), the crop yields were negatively affected by the increase in temperature with greater precipitation variation, particularly for cotton and sunflower. The exception was alfalfa because its yields did not consistently respond to climate change across the counties. Our results suggest that climate change will decrease crop yields in the long-term, particularly for cotton, unless greenhouse gas emissions and resulting climate change is curbed and/or adaptation of new management practices and improved cultivars occurs.

Annual soil C change was highly variable over time. Soil C storage did not differ between the climate change scenarios for the years 2010 to 2050 but tended to decrease more under A2 then B1 for years 2051-2097. Thus, soil CO_2 emissions were expected to increase in the same period under both climate change scenarios but soil C decomposition potentials would be higher under A2 compared with B1. Differences in N_2O flux between A2 and B1 did not show any apparent trend. This suggests that the effect of climate change on N_2O emissions was highly uncertain. Overall, global warming potential generally followed the changes in N_2O flux. However, the decrease in soil C was responsible for increasing global warming potential particularly for years 2050–2097.

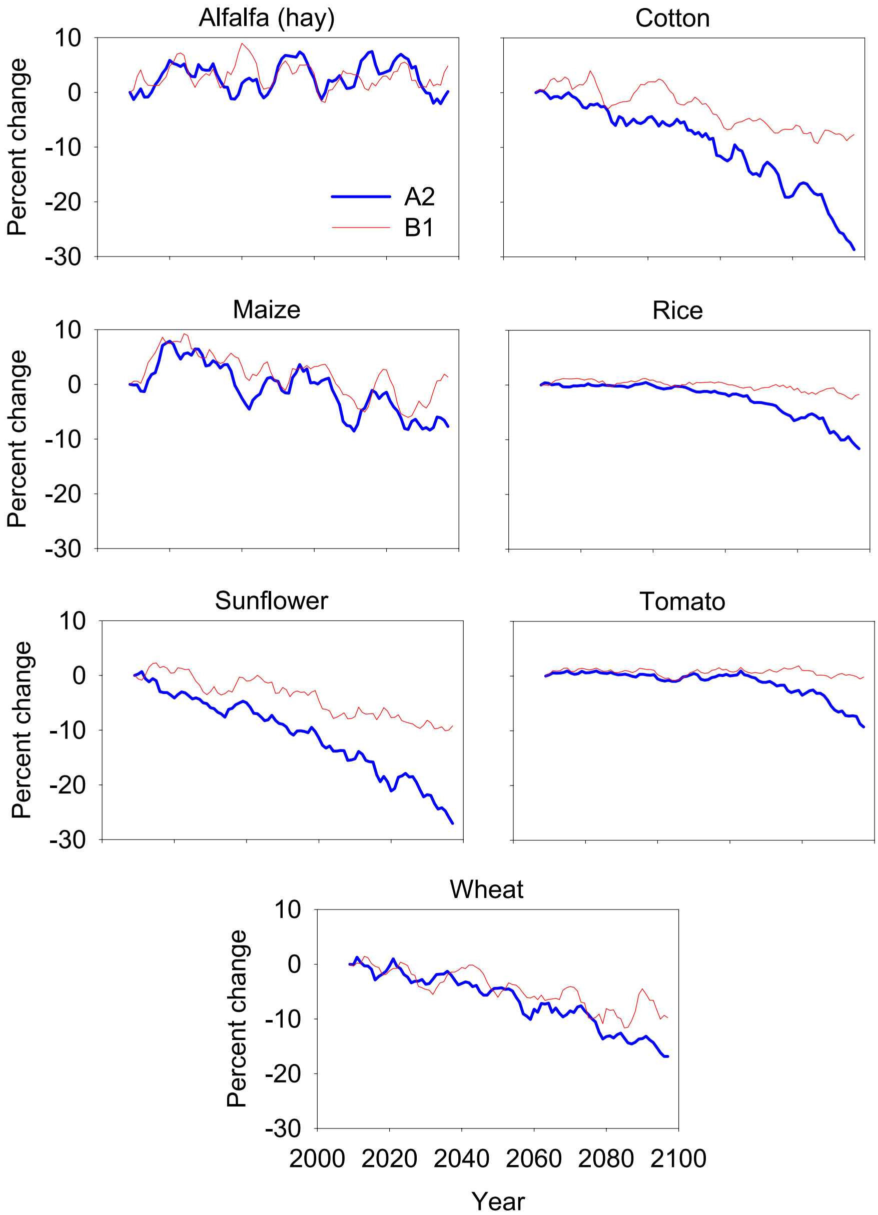

Figure 1. Changes in yield under A2 (medium-high) and B1 (low) emission scenarios. Five-year moving averages are calculated for the period from 2009 to 2097. Changes in yield are then expressed as percent deviation from the five-year moving averages in 2009.

Conclusion

The simulations suggest that future climate change under the different emission scenarios will lead to a broad range of impacts on yields of major crops grown in California. By 2097, yields under A2 decreased in comparison to the 2009 baseline in the following order: cotton (29%) > sunflower (27%) > wheat (17%) > rice (12%) > tomato (9%) > maize (8%).Yields were between 5% (alfalfa) and 21% (cotton) lower under A2 compared to B1. Greenhouse gas emissions are expected to be highly uncertain under climate change. In general, CO_2 flux did not differ between the climate change scenarios for the years 2000 to 2050 but tended to be higher under A2 then B1 for years 2051-2097. In the same period, N_2O flux did not differ between A2 and B1. Overall, global warming potential followed the trend of N_2O flux over time. However, the decrease in soil C was responsible for increasing global warming potential particularly for the years 2050–2097. In conclusion, climate change will decrease crop yields in the long-term, unless there are statewide adaptation scenarios and management strategies to climate change that maintain or increase yields while mitigating emissions of greenhouse gases.

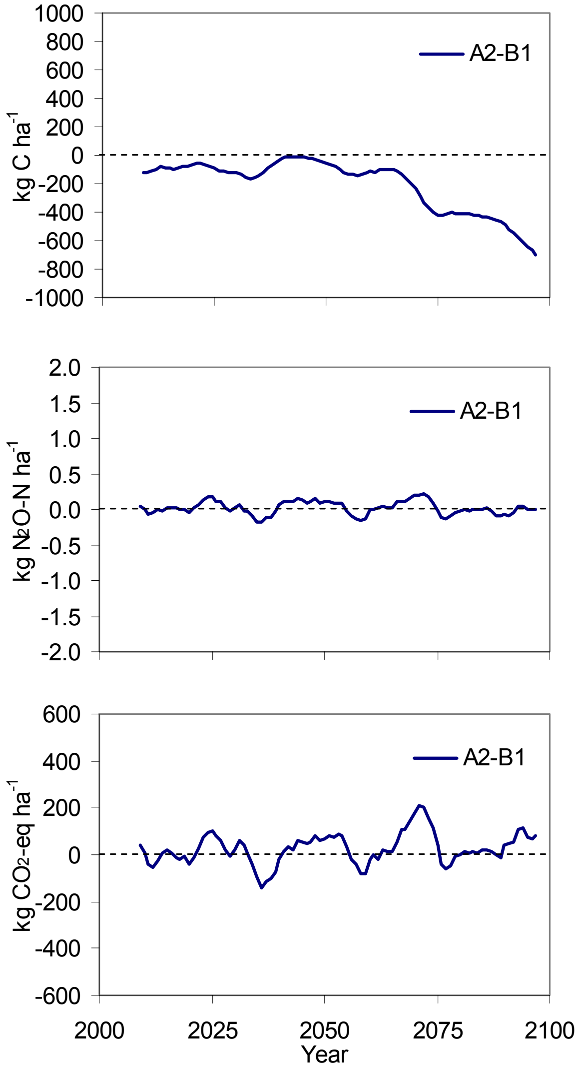

Figure 2. Modeled differences in soil C (top) and N_2O flux (middle), and global warming potential (bottom) between A2 and B1. 2009 average fluxes were used as baseline.

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