An Integrated Assessment of the Biophysical and Economic Potential for Greenhouse Gas Mitigation in California Agricultural Soils

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Summary

In California, concern for climate change has increased in recent years as it has become apparent that California’s climate is changing with more severe changes likely in the future. For example, it has been predicted that if current emission rates are maintained, heat waves will occur six to eight times more frequently, alpine/subalpine forest will be reduced by 75-90%, and the Sierra snow pack will decline by 73-90% by the end of the 21st Century. Predicted changes in climate are also expected to have dramatic consequences on air quality, human health, fire frequency, and summer energy demand. It is argued that changes in greenhouse gas emission rates in the near future have far-reaching implications for California’s climate in 2100. It is therefore of extreme importance to conduct comprehensive assessments of the biophysical and economic potential for C sequestration and mitigation of trace gas emissions in California.

Historically, agriculture has been a major source of CO2 and trace gases to the atmosphere. However, recent changes in agricultural practices aimed at soil conservation are believed to have stabilized soil C stocks, enhanced C sequestration, and reduced the rate of growth in trace gas emissions during the past few decades. Therefore, agricultural soils management has been advocated as a viable option in the portfolio of technologies needed to limit the increase in greenhouse gas concentrations over the next 50 years. However, before it will be considered a truly viable option, comprehensive assessments are needed that consider the net impact of changes in agricultural management on radiative forcing or global warming potential of all three major biogenic greenhouse gases and ancillary greenhouse gas changes due to changes in agricultural input (e.g., fuel usage).

A comprehensive assessment of the potential and efficacy of C sequestration and mitigation of trace gas emissions not only needs to consider the technical potential, but also the economic feasibility. It is pertinent to determine whether producers can mitigate greenhouse gas fluxes at a cost competitive with alternate approaches. Consequently, the coupling of site-specific ecosystem and economic simulation models is crucial.

Objective

Our overall objective is to assess the biophysical potential and economic feasibility for soil C sequestration and reduction of trace gas emissions in California agricultural soils through the integration of spatial databases on environmental factors and land use data with ecosystem simulation models and economic analyses.

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The proposed decision-support assessment tool will provide a more complete accounting of land use and management impacts on C stocks and associated CO₂, N₂O, and CH₄ fluxes between California agricultural soils and the atmosphere.

**Activities and Results**

**Ecosystem modeling**

In order to accurately model changes in yields and GHG emissions in California agriculture, we calibrated two models (DAYCENT and DNDC) and fully validated DAYCENT for yields. First, we calibrated the models for three experimental field sites maintained by the University of California, Davis, then we used county average yields to adjust and refine the crop parameters that were tuned using the field sites. We were quite successful in reproducing average yields of five major crops in Yolo County.

Once the calibration and validation was done for DAYCENT, we started using DAYCENT for regional projections. We modeled each of 2,000 unique crop rotation x weather x soil type combinations for the period 1997–2006 in Yolo County, California. We included six typical crops for the county (alfalfa, corn, safflower, sunflower, wheat, and tomato), cultivated in their typical rotations. For the regional projections, we considered reduced tillage, winter cover cropping, organic, and low-input practices, and compared these to conventional management practices.

In order to do the regional projections, we needed the most detailed input data that was available at the county scale. We accomplished this by developing databases on soil, crop type, crop rotation, management practices, and climate data.

**Soil data**

Soil data was extracted from SSURGO (Soil Survey Geographic Database). Estimates of soil physical parameters (e.g., texture, water holding capacity, potential rooting depth) were estimated from the GIS version of the county soil survey maps, available within the Soil Survey Geographic (SSURGO) database.

**Crop types and rotations**

To determine spatially explicit land use, we used the land-use GIS developed by California Department of Water Resources (DWR). This product is a GIS database with detailed maps of crop locations and crop type, derived from analyses of aerial photos and field surveys. After consultation of farm advisors and analysis of the 2000 to 2005 pesticide use report data from Yolo County agricultural commissioners, we selected five typical rotations: tomato-wheat, corn-tomato-wheat, 4 x alfalfa-tomato-wheat, sunflower-tomato-wheat, and safflower-tomato-wheat. We calculated the probability of each field being in a specific rotation, based on the acreages of these crops calculated from the DWR GIS. For each of the field parcels in the DWR GIS, we randomly assigned a rotation according to these probabilities.
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 (AgRIC; http://agric.ucdavis.edu/), and the cost and return studies available through the University of California Cooperative Extension (http://coststudies.ucdavis.edu/). Next to conventional farming, we considered three alternative practices: winter cover cropping, organic, and reduced tillage. Information on the management of these alternative cropping practices was obtained from farm advisors and the Long Term Research of Agricultural Systems (LTRAS) at Russell Ranch of the University of California, Davis.

Climate data

Spatially explicit climate data was extracted using the DAYMET model (www.daymet.org), developed at the Numerical Terradynamic Simulation Group of the University of Montana. This model uses a digital elevation model and daily observations from ground-based meteorological stations to produce a daily data set of temperature, precipitation, humidity and radiation. Our strategy was to model each separate unique combination of soils, crop type, and microclimate. An overlay was created in ArcGIS version 9 of the GIS soil information from SSURGO, the crop information from DWR, and the gridded climate data from DAYMET. The result of this overlay was a database containing 11,611 unique combinations of soils, crops and climates. In the overlay procedure, a lot of very small polygons were created, not meaningful to the results at a regional level. Therefore, due to modeling time constraints, we omitted the 25% smallest fields, comprising only 5% of the total area of the county.

A framework was developed to easily create all the input files necessary to run the DAYCENT model for each of these units. This framework also automatically collected the model results and calculates sums and averages of each of the output parameters of interest. This framework allows us to easily carry out a large number of simulations over different gradients of soils, climates, crops, and managements and interactions of these. The model itself was run on a 14-CPU UNIX cluster at the Biocomputing Center of the Plant Sciences Department at the University of California, Davis.

Crop phenology and growing patterns were calibrated using county average yield data from the NASS, biomass C, and N data from two long-term agricultural experiments in the county (LTRAS and SAFS), and C allocation to shoots and roots and nitrogen dynamics data from various literature sources. These values were confirmed with model results from the DSSAT/CERES plant growth model, using the climate and soil conditions of Yolo County (ICASA, 2004).

Results

Our simulations indicated that reduced tillage management had minimal effect on yields. This management led to an increase in GHG emissions for wheat (about 0.3 Mg CO$_2$-eq ha$^{-1}$ yr$^{-1}$), and reductions for the other crops. The reductions were similar for corn, safflower, and sunflower, and averaged around 1 Mg CO$_2$-eq ha$^{-1}$ yr$^{-1}$. The reductions were larger for tomatoes (3.6 Mg
CO2-eq ha\(^{-1}\) yr\(^{-1}\)). All crops showed a net decrease in N\(_2\)O emissions; however, there was no consistent trend in the contribution to the GWP of CO\(_2\) and N\(_2\)O.

Winter cover cropping led to small reductions in yield for tomatoes about 3\%, the other crops were minimally affected. For all crops under this management, there was a reduction in GHG emission ranging from 0.7 to 3.3 Mg CO\(_2\)-eq ha\(^{-1}\) yr\(^{-1}\). Winter-grown wheat, within a winter cover cropping rotation, was associated with a decrease in GHG of 0.2 Mg CO\(_2\)-eq ha\(^{-1}\) yr\(^{-1}\). The contributions to the GWP were mainly coming from increases in SOC. For almost all crops (except sunflower), there was a net increase in N\(_2\)O emissions, ranging from 69 Mg CO\(_2\)-eq ha\(^{-1}\) yr\(^{-1}\) for corn to 514 Mg CO\(_2\)-eq ha\(^{-1}\) yr\(^{-1}\) for safflower.

Implementing organic management reduced the sunflower, tomato, and wheat yields somewhat (3–4\%); the other crop yields were even less affected. The GWP decreased for all crops. This decrease was largest for corn and sunflower (4.8 Mg CO\(_2\)-eq ha\(^{-1}\) yr\(^{-1}\)), followed by tomatoes (4.2 Mg CO\(_2\)-eq ha\(^{-1}\) yr\(^{-1}\)), safflower (3.1 Mg CO\(_2\)-eq ha\(^{-1}\) yr\(^{-1}\)), and wheat (1.2 Mg CO\(_2\)-eq ha\(^{-1}\) yr\(^{-1}\)). The reductions were both due to an increase in SOC and a decrease in N\(_2\)O emissions (16 to 57\%).

We found that a low-input system did not affect yields, except for safflower. The GHG emissions decreased between 0.2 and 2.3 Mg CO\(_2\)-eq ha\(^{-1}\) yr\(^{-1}\). All of this decrease was due to reductions in N\(_2\)O emissions.

We concluded that organic agriculture was an efficient option to reduce GHG emissions, especially for rotations that include corn. The use of winter cover cropping is also a viable option but mainly in the short-term, because its GHG mitigation potential is mainly based on increases in soil C, and soils are limited in their capacity to store soil C. Decreases in GHG emissions for reduced tillage were associated with net decreases in N\(_2\)O emissions (especially for corn and tomatoes), and therefore viable options for C sequestration. Although the GHG mitigation potential was smallest for low-input systems, this was almost completely due to reductions in N\(_2\)O emissions, and therefore permanent. Low-input systems are an efficient and low-cost alternative for crop rotations and at any time-scale.

**Economic Modeling**

**Activities**

The activities undertaken have been directed:

1) To identify and apply a methodology required to build an economic model that helps to assess, from past observed data, a conservation policy that pays farmers to adopt greenhouse-gases mitigation management systems in California agricultural soils. The economic model has two goals:

A) To couple agronomic models and data in a way that the economics and the agronomics form a system that reproduces and accurately simulates both farmers’ field decisions and the dynamics of the greenhouse gas fluxes.

B) To capture the heterogeneity of farmers and soils so that they can be aggregated consistently to determine a schedule of payments that will achieve C sequestration.
To accomplish these goals we followed the *quantitative integrated assessment* methodology, i.e., the use of linked disciplinary simulation models to evaluate complex natural and human systems. The final output of the integrated assessment will be a regional carbon sequestration supply curve.

2) To identify the data and construct a database that integrates all the inputs needed to predict, in the most accurate way, the effects of the aforementioned conservation policy. The construction of the database has three main purposes:

A) To satisfy the specific needs of the economic modeling, but at the same time to improve the accuracy of the results of site-specific, agronomic modeling.

B) To identify the characteristics of other geographical regions in Northern California that can be studied and modeled given time and economic constraints.

C) To estimate consistency rules that will allow for future extensions of the data to new regions.

Goal A puts together economic and agronomic knowledge in the most integrated and precise way. Goal B makes a realistic use of the available resources to determine the geographical extension of the study and to determine geographical units that can be feasibly incorporated into the study. Goal C acknowledges the diversity in agricultural systems in California, and the specificity of each region incorporated, according to goal B.

**Results**

Data gathered from experimental plots and their corresponding budgets from LTRAS (1994-2004), SAFS (1989-2000) and Five Points (2000-2004), revealed that the analysis was not homogeneous among sites, not only from the already-mentioned agronomic standpoint, but also from the economic one. The computation of a mitigation price using budget reports on returns and costs of operation led to the following results:

1) In LTRAS, to switch from conventional tillage to low-input conservation tillage implied GHGs savings of 2.86 MgCO$_2$e yr$^{-1}$ ha$^{-1}$ and a mitigation price of $22. To switch from conventional tillage to an organic system led to GHGs savings of 6.5 MgCO$_2$e yr$^{-1}$ ha$^{-1}$ with an increase in net profits, i.e., with an associated mitigation price of $0! 

2) In SAFS, to switch from conventional tillage to low-input conservation tillage implied GHGs savings of 3.33 MgCO$_2$e yr$^{-1}$ ha$^{-1}$ and a mitigation price of $18.

3) In Five Points, to switch from conventional practices to cover cropping resulted in GHGs savings of 5.21 MgCO$_2$e yr$^{-1}$ ha$^{-1}$ and a mitigation price of $35. To adopt conservation tillage with no cover cropping, the savings were 2.87 MgCO$_2$e yr$^{-1}$ ha$^{-1}$ and required no compensation to the farmer. Finally, to adopt conservation tillage with cover cropping required 10.39 MgCO$_2$e yr$^{-1}$ ha$^{-1}$ with a mitigation price of $35.

These results let us to conclude that economic analyses were very sensitive to site-specific characteristics and management. Also, we detected internal inconsistencies related to the relevance of fixed costs for mitigating practices, since in some sites the same practice will have a significant impact on mitigation prices while in others it will have no effect. Although some missing data in the budgets for some years could add such noise to the analysis, the main reason not to solely rely on experimental data was that actual managerial skills and preference for
farmers in a complex economic environment cannot be captured in experimental data. Since the experimental sites are not run by real farmers taking decisions in accordance with the economic environment, we were unable to incorporate farmers’ preferences into the analysis. Also, farmers respond to expected prices and make their crop choice for a given field based on profit maximization criteria. All these important factors were missing in the experimental data. Therefore, we decided to conduct a survey with local farmers on management practices, costs, and yields. These surveys will be reported on at a later date.

**Manuscripts**


**Presentations**


Six, J. 2005. Carbon cycling in conservation agriculture: From the microscale to the regional scale. CIMMYT, Mexico City.

Outreach


March 11, 2006. Provided written and phone interview information on conservation tillage to Susan McEntire. Chief of Staff for Assemblyman Ira Ruskin. California State Assembly


January 30, 2006. Conservation tillage – an emerging tool for sustainable production in California. Invited seminar presentation as part of “Sustainability Month at Cal Poly: Resolve to change your world.” California Polytechnic State University, San Luis Obispo. 30 participants.


December 1, 1005. Improving San Joaquin Valley air quality by the use of conservation tillage production systems. Invited oral presentation to Valley Clean Air Now. Greater Bakersfield Chamber of Commerce, Bakersfield, CA. 20 participants.


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