2015

Cultivating conservation: Bringing ecology, economics and ethics together

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Abstract
Most current modeling frameworks have a limited view when gauging the response of an agroecosystem to different stressors. They tend to focus individually on either productivity in terms of crop yield, or profit, in terms of net income. However, if the framework does not include a means to assess the overall health of the agroecosystem, it will provide only a short-range sense of food security. The current practices may initially provide a spike in yield or income, but they also may mask the slow but ongoing degradation of the soil.

Keywords
Economic and environmental impacts, Models and assessment tools

Disciplines
Natural Resource Economics | Natural Resources and Conservation | Natural Resources Management and Policy

LEOPOLD CENTER
FOR SUSTAINABLE AGRICULTURE

'Cultivating' Conservation: Bringing Ecology, Economics, and Ethics Together

Abstract:

Most current modeling frameworks have a limited view when gauging the response of an agroecosystem to different stressors. They tend to focus individually on either productivity in terms of crop yield, or profit, in terms of net income. However, if the framework does not include a means to assess the overall health of the agroecosystem, it will provide only a short-range sense of food security. The current practices may initially provide a spike in yield or income, but they also may mask the slow but ongoing degradation of the soil.

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Budget:
$26,751 for year one

Q How can we measure how well current and potential future land stewardship decisions balance system productivity, farmer financial gains, and overall system health?

CROSS-CUTTING

A The PIs developed an integrated ecological-economic modeling framework that examines the production of different ecosystem services including crop productivity, carbon storage, CO_2 fluxes, and net income for current practices using different metrics. One metric that proved to be most responsive to different climate and land management drivers was the Carbon Management Index (CMI). The CMI is a valuable addition to the list of metrics as it provides a good measure of how sustainable a practice can be. In this case, it appears that the least intensive tillage practice is best for sustaining productivity. This is due to the combination of the Carbon Pool Index (CPI), which captures the level of the management disturbance through the loss of Soil Organic Carbon (SOC) compared to a reference value, with the Lability Index (LI) which reflects the type of carbon being stored in the system.

Background

As the earth's population skyrockets toward nine billion people by 2050, food production needs to increase by nearly 70 percent to satisfy global needs. Through agro-technical advances and crop breeding, productivity has increased. But as production rises, the intensive management and continuous fertilization are degrading agroecosystems and threatening their sustainability.

The central objective for this study is to develop a means of assessing how well current and potential future land stewardship decisions balance system productivity, farmer financial gains, and overall system health using an integrated ecological-economic modeling framework. The PIs suggest that most modeling frameworks take a limited view and fail to assess overall system health. The need to sustain in Iowa a healthy soil, or a soil that effectively functions to produce multiple ecosystem services is critical because soil condition is the primary factor in the short- and long-term productivity of the agroecosystem.

In this project, SOC was used as a common thread to link the different functions of agroecosystems (e.g., food security, greenhouse gas regulation, climate regulation). Due to its close and well-established relationship to local soil biogeochemical controls and processes, SOC strongly influences soil quality, crop yields, net income, and other ecosystem services. It offers an appropriate measure for quantifying and assessing the effects of land management practices on overall system health in Iowa agroecosystems. The framework was used to develop a carbon budget for Iowa's Clear Creek watershed located in Iowa and Johnson counties. The carbon budget

was used to determine the other factors related to farmer financial gains and overall system health in an agroecosystem.

Approach and methods

The modeling framework used here differs from other current frameworks. It incorporates a bottom-up approach that integrates two established, process-based erosion models, the Water Erosion Prediction Project (WEPP) and the CENTURY biogeochemical model, to capture the variability of soil biophysical properties that shape the landscape's productivity. Then a landscape-oriented approach was used to consider the effects of runoff and erosion on SOC storage along a hillslope, in light of the different tillage and fertilizer schedules and tiles. These models were coupled with a simple but effective economic model that determines net revenues from different crop rotations. It includes a premium that provides economic benefits for reducing erosion and promoting different ecosystem services related to C storage.

The bottom-up approach promotes better understanding of how landscape properties, management, and climate can interact to affect runoff, soil erosion, the C cycle, system productivity, and net income. All of these factors relate to productivity, farmer financial gains, and overall system health.

These were the project actions that addressed the central objective:

- Develop an ecological-economic modeling framework that examines system productivity, farmer financial gains, and overall system health in an agroecosystem.
- Identify metrics that characterize multiple ecosystem services related to productivity, farm economics, and system health.
- Develop future land management scenarios that are meaningful to Iowa.
- Quantify and map metrics at watershed scale.
- Grade the systems responses to different management rotations based on metric scores (normalized) as a report card.

Results and discussion

This study examined three different management rotations currently practiced in Clear Creek that had varying degrees of tillage intensity. The rotation with the highest tillage intensity produced the highest yields, but the corresponding high production costs kept net incomes low. The second most intense practice also had high yields, as well as the highest net income.

However, the drawback to these two rotations was the accompanying high erosion rates. These erosion rates are captured through the T-value, or the maximum rate of erosion at which the quality of a soil as a medium for plant growth can be maintained. For these rotations, less than a quarter of the practicing hillslopes had erosion rates less than the T-value, with more than a third of the hillslopes having values more than double the T-value. High erosion depletes soil organic matter and other nutrients such as phosphorus. Over time, it will require additional money and effort to sustain the high productivity due to the loss of nutrient-rich soils.

For the least intense rotation, almost half of the hillslopes (45 percent) had erosion

rates less than the T-value and only 14 percent of the hillslopes had values more than twice the T-value. The farms with the highest yields were neither profitable nor sustainable in the long term with negative projections on farmer income and land productivity due to soil organic matter depletion.

Conclusions

Based on this study, it is important to note that when developing future land management scenarios for Iowa, one must consider those practices that promote SOC production in the soil. These practices include conservation tillage, cover crops, multiple crop rotations, manure applications, and precision farming, which can be readily implemented by the farmer as they rely more on the farmer rather than on institutional help. Hence when developing a message for farmers, two things need to be stressed: (1) work to improve overall system health by implementing practices that build up SOC, and (2) these SOC-building practices can be implemented by the farmers through their own efforts in light of dwindling incentives.

A new aspect of this study is the use of the Carbon Management Index (CMI), which was determined for the different hillslopes in Clear Creek. The CMI is a valuable addition to the list of metrics for overall system health. It provides a good measure of how sustainable a practice can be, and in this case it appears that the least intense practice is best for sustaining the productivity of the field. This is due to the combination of the Carbon Pool Index (CPI), which captures the level of the management disturbance through the loss of SOC compared to a reference value, with the Lability Index (LI) which reflects the type of carbon being stored in the system.

The CMI for each rotation increased over the last 20 years, which is about the length of time that they have been practiced in the watershed. However, the CMI for the two more intensive rotations began to decrease in recent years. The downward trend is a reflection that these rotations are not sustainable, despite being more productive or providing the highest net income in the short term. The least intensive tillage schedule helped minimize the depletion of SOC through erosion. As a result, it has the highest QCMI at the end of the period and the trend is still increasing.

Impact of results

The team sought to develop a means to assess how well current and future land stewardship decisions balance system productivity, farmer financial gains, and overall system health using an integrated ecological-economic modeling framework. The framework in the study transcends existing methods as it uses a bottom-up approach that integrates two established, process-based models, WEPP and CENTURY. The bottom-up approach better captures the overall effects of spatial heterogeneity in terms of flow, soil properties, land use/land cover, and hillslope curvature on erosion for different events, seasonal and inter-annual periods. Collectively, the models can accurately quantify the effects of different land management practices on soil health within a field. The coupling of the two models also allows researchers to overcome the limitations of the current methods to quantify carbon budgets which do not account for erosion.

The framework adds a correction to account for erosion directly in the NEE equation, which was used for the carbon budgets. In addition, the effects of erosion and

implications for respiration and production are accounted for through the changes in SOC stock. It is important to note that the erosion results from the interplay of climate and land management practices.

Finally, this framework can be used to determine the Carbon Management Index (CMI), which is a good measure of how sustainable a practice can be. The CMI captures both the level of the management disturbance through the loss of SOC compared to a reference value, and a reflection of the type of carbon being stored in the system.

Education and outreach

This proposal supported a portion of Ken Wacha's Ph.D. dissertation that focused on the benefits of multifunctional agriculture. The PIs promoted this work at the American Geophysical Union fall meetings in 2014 and December 2015. Additionally, information about this work was presented at the 2014 Environmental Water Resource Institute Congress in Portland, Oregon.

Finally, through the Intensively Managed Landscapes-Critical Zone Observatory (IML-CZO), the project team has been able to expand this study from a small sub-watershed to all of Clear Creek, a more meaningful size in terms of policy-related issues. One of the key aspects of the national CZO program is to develop an interdisciplinary understanding of the processes driving critical zone services between the bedrock and the top of the canopy. This project allowed them to develop further those tools needed for capturing the benefits of these services. The role of the IML-CZO in the National Science Foundation program offers national exposure to the effects of land management on SOC and soil health.

Leveraged funds

The project efforts stem from a joint National Aeronautics and Space Association (NASA) Experimental Program to Stimulate Competitive Research (EPSCoR) project between the PI and the Leopold Center, entitled "Agricultural Soil Erosion and Carbon Cycle Observations in Iowa: Gaps Threaten Climate Mitigating Policies." The overarching goal for the NASA EPSCoR project is to build research capacity within the state of Iowa and the Midwest for investigating the impacts of land use change and agricultural practices on the region's SOC sequestration potential. The current study was enhanced by the experiences gained through the NASA EPSCoR project in terms of understanding the importance of erosion in carbon budgets. The study also extends the NASA work by examining the other ecosystem benefits related to carbon and SOC.

In addition, the current study utilizes much of the data collected through National Science Foundation CZO that was established in Clear Creek. The IML-CZO has extensive geospatial, chemical, and eco-hydrological databases, as well as a detailed history of land uses and management practices in Clear Creek. These data were used in the ecological-economic modeling framework to develop carbon budgets.

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