Gaming Ag Nitrogen Cycling

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Abstract
Students apply the Law of Conservation of Mass to understand nitrogen (N) budgets for a Corn-belt agricultural system at the plot level. A 45-minute, in-class introduction enables students to complete an outside-of-class activity using a process-based simulation model in 'lab mode' address 'What-If' questions about effects of various management practices on N cycling. Then, during one 75-minute class, teams use the model in a game-like mode to compete in attaining four different goals: 1) Maximize income; 2) Increase soil carbon; 3) Reduce nitrate flow to streams; and 4) Optimize yield and soil organic N while reducing N in streams.

Disciplines
Educational Methods | Natural Resources Management and Policy | Science and Mathematics Education

Comments
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EXPERIMENTS

Gaming Ag Nitrogen Cycling

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ABSTRACT

Students apply the Law of Conservation of Mass to understand nitrogen (N) budgets for a Corn-belt agricultural system at the plot level. A 45-minute, in-class introduction enables students to complete an outside-of-class activity using a process-based simulation model in 'lab mode' address 'What-If' questions about effects of various management practices on N cycling. Then, during one 75-minute class, teams use the model in a game-like mode to compete in attaining four different goals: 1) Maximize income; 2) Increase soil carbon; 3) Reduce nitrate flow to streams; and 4) Optimize yield and soil organic N while reducing N in streams.

KEYWORD DESCRIPTORS

- **Ecological Topic Keywords:** Biogeochemical cycles, denitrification, ecosystems, eutrophication, nitrogen cycle, nitrogen fixation, productivity, nitrogen cycling, soil dynamics
- **Science Methodological Skills Keywords:** Scenario design, model use, oral presentation
- **Pedagogical Methods Keywords:** Cooperative learning groups; games to teach ecology guided inquiry; problem-based learning; Team-Based Learning

CLASS TIME

120 minutes total; 45 minutes introduction to the individual activity during one class period, then 75 minutes during the next class meeting time.

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OUTSIDE OF CLASS TIME

30-60 minutes

STUDENT PRODUCTS

For the individual activity done outside of class, students will complete the tables in the handout, based on data collected from their model runs and interpret the results in words. For the team-based part of the activity, they will fill in data in the tables in the handouts, based on their model runs. During a class-wide discussion at the end, students will discuss their reasoning for the management practices they selected for modeling, and the implications for regional issues, such as hypoxia in the Gulf of Mexico.

SETTING

Because this is a simulation modeling activity, it can be done anywhere indoors. They will need the internet to download the model at the beginning, but once it is on their laptop, they can work anywhere.

COURSE CONTEXT

This can be used in any Introductory Biology or Introductory Ecology course, or even more advanced courses because this topic is often not covered in introductory courses. It can be used in a lecture or a laboratory section of a course. The activity works best after the topic of biogeochemical cycles has been covered. I have used this for courses of 6 to 80 students.

INSTITUTION

I have used this in three different courses at a large, public university.

TRANSFERABILITY

The simulation model was designed to be very user friendly, and the home website is equipped with an introductory video, with the goal of making the activity accessible for non-majors and pre-college students. The video has closed captioning. While the setting is midwestern-US centric, element budgeting is a broad concept that can be transferred to any ecosystem. As long as internet access is available, this activity is accessible.

ACKNOWLEDGEMENTS

My guiding inspiration is from H.T. Odum. It has been a while since he passed away, but his creative spirit continues to be a daily source of inspiration that the world is a dynamic place - and it’s fun to model it. Without the talents and patience of Jim Dailey, my ideas would never have reached fruition, however. We also thank our collaborators, Mike Castellano, Matt Helmers, Tom Isenhart, Lisa Schulte-Moore, and Richard Schultz for their guidance about data for the model and feedback. We also thank Ann Greazel and John Van Dyke for the website development and Mike Castellano for peer review. Funding for this project was provided by ISU's College of Agriculture & Life Sciences Technical Advancement Committee, ISU's Department of Natural Resource Ecology & Management, and the NIFA Multistate Project No. NC1195.

SYNOPSIS OF THE EXPERIMENT

Principal Ecological Question Addressed

What are the effects of management practices on nitrogen (N) cycling in an agricultural system?

What Happens

Students design simulation modeling scenarios to address ‘What-If’ questions about the effects of management practices on N stocks and fluxes in a Corn-belt agricultural system. They decide which parameters to vary to answer the questions posed. They conduct the model runs for three different Scenarios and gather data from the simulations. They interpret the results at a local scale and discuss consequences at the regional scale.

Modeling Objectives

1. Understand that by the Law of Conservation of Mass, the mass of an element is neither created nor destroyed. Thus, as nitrogen (N) cycles, it flows between stocks (= reservoirs, pools, stores, storages), but the sum across all stocks remains constant. This allows us to work with budgets for elements.
2. Learn how we can use simulation models to pose ‘What-if?’ questions and to explore different Scenarios about the effects of management on N cycling in agricultural system. This includes questions about cropping system, N fertilizer addition, tilled vs no-till, cover crops and riparian buffer strips.
3. Gain an understanding of how local management can influence soil health, and local and regional water and air pollution.
4. Understand about trade-offs among crop productivity, management factors, and N cycling.

Equipment/ Logistics Required

A laptop and internet access for downloading the model.

Summary of What is Due

1) Completed individual assignment (Tables 1 and 2 filled in with data, and text for interpretation of results). Note that we complete Table 1 and part 1 of Table 2 as a class during the 45-min introduction to the assignment. 2) Completed Team activity (Tables 1-4) plus participation in class discussion.

DETAILED DESCRIPTION OF THE EXPERIMENT

Introduction

As the main component of proteins, nitrogen (N) is required by all living organisms. Nitrogen is abundant in the atmosphere, which is 79% N, but mostly as a stable, unreactive gas (N_2). Reactive N that is available for plant growth is often in short supply, however. In agricultural systems, addition of fertilizer N can increase crop production and as a result, improve human nutrition. On the other hand, excess fertilizer N can have deleterious effects on air and water, and thus on human health. Here's the challenge: Can you manage the agricultural system for crop production without negative impacts for nitrate run-off to streams and greenhouse gas production?

To guide our understanding of these trade-offs, we have developed a simulation model of cropping systems in north central Iowa to track nitrogen as it cycles between stocks, also known as reservoirs or pools, that represent the quantity of matter defined per unit of space. Flows represent the quantity of matter moving between stocks per unit of space and time. The model is based on data from research in this region. The model will allow us to explore different management scenarios and ask 'What-if' questions about the effects of crop and soil management options, and climate change, on N cycling. The goals are to develop N budgets and understand principles that guide management for crop productivity, soil conservation, and nitrate pollution reduction in streamflow. The modeling will also provide insight into how management at the local level influences regional and global nitrogen cycling.

By the Law of Conservation of Mass, the total N mass in the system, summed across all the stocks, is constant. However, because N cycles, the amount within each individual stock can change. We can use this principle to experiment with how to maximize stocks that users wish to improve (Yield, Soil Organic N), and minimize stocks with deleterious effects (nitrous oxide, a greenhouse gas that can be produced during denitrification, and N loss to Streams). Students can design simulation Scenarios to explore questions about the effects of cropping system, management, and climate change on N cycling by manipulating the variables described above. Over the course of multiple model runs, students can collect data from the model output to address various questions about effects of management and climate change on N cycling in an agricultural setting.

Three management practices used in the model can potentially reduce soil inorganic N stocks, thereby reducing N available to be leached to the stream. Two of the practices can assimilate N not taken up by the crop: 1) cover crops that are typically planted after crop harvest and harvested before the next crop is planted and 2) riparian buffer strips planted between the crop field and the stream. The use of no-till reduces soil disturbance, potentially reducing mineralization of soil organic N to inorganic N.

Here is the link to an Introductory Video: https://youtu.be/hbHCyktxGus

Also, please see these powerpoints:

- "Background_The Nitrogen Cycle in an Agricultural System.pptx"
- "Individual Activity_N Model for IA Ag.pptx"
- "Team Activity_Gaming Ag N Cycling.pptx"

Materials and Methods
Study Site(s):

The virtual setting for this activity is a farm on silty clay loam soil in north Central Iowa. The simulation model for this activity is available at: https://www.nrem.iastate.edu/nmodel/how-run-model. The model contains six main stocks, seven flows and various management practice options, and a water sub-model. The model can be run using either deterministic or stochastic data for temperature and precipitation, which are based on 20-year monthly means for the area. The user can adjust temperature and precipitation for predicted climate change in this area.

Please see the website, https://www.nrem.iastate.edu/nmodel/ or the powerpoint ("Individual Activity_N Model for IA Ag.pptx") for a description of the model.

Overview of Data Collection and Analysis Methods:

The student handout for the Individual Activity, "Individual Activity_N Model for IA Ag.docx" provides a description for collecting data to explore the Law of Conservation of Mass (Part A) and address 'What-If questions about three different scenarios (Part B). The scenario descriptions provide the information for students to choose the baseline 'Initial' parameters. Students run the model using the 'Deterministic' setting for randomness of climate data, and record output data gathered at the end of one 10-yr-long run. Students decide which parameter to change, based on the question posed, and then run the model again and gather output data after this 'Final' model run. The answer key is given in "Individual Activity_N Model for IA Ag_Expert answers.docx."

The student handout, "Team Activity_Gaming Ag N Cycling.docx" explains data collection for the Team activity. Students can change any number of parameters at the beginning of each year of the 10-yr run. They record the parameter settings at the beginning of each year and the output data at the end of each year.

The individual activity was designed for a 45-minute class period, so this activity does not involve stochasticity in climate data; students use the 'Randomness' setting at 'Deterministic.' If a longer class time is possible, this activity could be done using the 'Stochastic Temp & Rain' setting for Randomness, which will introduce variability in the output data. Students would make multiple models runs under each set of parameter settings. This replication within a given set of management conditions would provide data for conducting statistical analyses. Because the stochasticity for the climate data is based on monthly meterological records for the 20 years for the area, they represent natural variability in climate drivers for N cycling at the site.

Questions for Further Thought and Discussion:

1. If N fertilizer inputs to corn are reduced, what is the effect on crop yield? On nitrate fluxes to streams? On soil organic matter (SOM)?
2. What are some management practices that reduce nitrate fluxes to streams?
3. Why might SOM decline if fertilizer inputs were reduced? How did you use the concept of N budgets to answer this question?
4. Would you expect SOM to increase under alfalfa, even without N fertilizer addition? Why or why not?
5. How does excessive nitrate flow from streams in the midwestern Corn Belt relate to hypoxia in the Gulf of Mexico? (See Vitousek et al. 2009, Howarth et al. 2011)
6. What do you expect would happen if precipitation changed?

References

Christianson, L., J. Tyndall, and M. Helmers. 2013. Financial comparison of seven nitrate reduction strategies for Midwestern agricultural drainage. Water Resources and Economics **2**:30-56.

Howarth, R., Chan, F., Conley, D. J., Garnier, J., Doney, S. C., Marino, R. and G. Billen. 2011. Coupled biogeochemical cycles: eutrophication and hypoxia in temperate estuaries and coastal marine ecosystems. Frontiers in Ecology and the Environment **9**:18-26.

Lawlor, P. A., M. J. Helmers, J. L. Baker, S. W. Melvin, and D. W. Lemke. 2008. Nitrogen application rate effect on nitrate-nitrogen concentration and loss in subsurface drainage for a corn-soybean rotation. Transactions of the ASABE **51**:83-94.

Mitsch, W. J., J. W. Day, J. W. Gilliam, P. M. Groffman, D. L. Hey, G. W. Randall, and N. Wang. 2001. Reducing Nitrogen Loading to the Gulf of Mexico from the Mississippi River Basin: Strategies to Counter a Persistent Ecological Problem: Ecotechnology—the use of natural ecosystems to solve environmental problems—should be a part of efforts to shrink the zone of hypoxia in the Gulf of Mexico. AIBS Bulletin **51**:373-388.

N model for Iowa Agricultural Systems website: https://www.nrem.iastate.edu/nmodel/

Russell, A. E., D. A. Laird, T. B. Parkin, and A. P. Mallarino. 2005. Impact of nitrogen fertilization and cropping system on carbon sequestration in midwestern Mollisols. Soil Science Society of America Journal **69**:413-422

Russell, A. E., C. A. Cambardella, D. A. Laird, D. B. Jaynes, and D. W. Meek. 2009. Nitrogen fertilizer effects on soil carbon balances in Midwestern US agricultural systems. Ecological Applications **19**:1102-1113.

Vitousek, P. M., R. Naylor, T. Crews, M. David, L. Drinkwater, E. Holland, P. Johnes, J. Katzenberger, L. Martinelli, and P. Matson. 2009. Nutrient imbalances in agricultural development. Science **324**:1519-1520.

Tools for Assessment of Student Learning Outcomes:
Please see the following handouts for this activity:

- Individual Activity_N Model for IA Ag.docx
- Individual Activity_N Model for IA Ag_expert answers.docx
- N in IA Ag model worksheet.xlsx
- N in IA Ag model worksheet_Answer key.xlsx
- Team Activity_Gaming Ag N Cycling.docx
- Team Activity_Gaming Ag N Cycling_Plausible answers.docx
- Rubric for Individual and Team Activities.docx

A quiz that can be given as a pre- and post-test to evaluate learning that results from this activity:

- Nitrogen cycling pre- and post-test.docx
- Nitrogen cycling pre- and post-test_answer key.docx

NOTES TO FACULTY

Challenges to Anticipate and Solve

1. For the team-based part of the activity, the biggest challenge is if >20 students access the model in the cloud simultaneously. This causes the model to run slowly and stall. One solution is to encourage students, by awarding points if necessary, to download the model onto their laptop before class, and use the model from their laptop, rather than from the cloud. If the course maintains a set of laptops for student use, another solution is for the instructor to download the model onto those laptops prior to the team activity.

2. Accomplishing all four games can be a challenge because students can tend to linger over an individual game. The solution is to display a (e. g., https://www.online-stopwatch.com/rocket-timer/) on the main screen for the class at the beginning of each game, so that students can gauge their time. That way, finishing the model runs in time can add to the excitement and become part of the game. Also, it helps if the instructor is able to have an undergraduate TA who can circulate the room along with the instructor to assist students if they are having issues.

3. Not every student will have completed the individual assignment which prepares them to do the team-based part, slowing down that part. The solution is to work through the first part of the individual assignment as a class and leave time at the end for them to complete the assignment while they are still in class. Again, if an undergraduate TA is available, they can help the instructor assist students with issues.

Comments on Introducing the Experiment to Your Students:

I introduce the individual activity, using the powerpoint "Individual Activity_N model for IA Ag.pptx" and the team activity using the powerpoint "Team Activity_Gaming Ag N Cycling.pptx."

Comments on Questions for Further Thought:

For the Individual Activity:

1. Consider the following situation. A farmer applies a certain amount of N fertilizer as inorganic N at the beginning of the growing season. High rainfall and cold, cloudy conditions then occur all summer long, reducing the crop's ability to take up N, and reducing crop yield. In what stock(s) in this ecosystem would you expect to find the excess N that was not in crop yield this year?

Expert answer: In the stream and/or atmosphere.

2. What Law guided your answer above and why?

Expert answer: Law of Conservation of Mass. Because N would be neither created nor destroyed, the N that was not taken up by the crops had to have flowed to some other stock. Inorganic N is very reactive, and most likely to be transported to the stream or to the atmosphere via denitrification. Microbes may also have assimilated (immobilized) some N to increase the stock of soil organic N.

3. Why would these wet conditions promote denitrification?

Expert answer: Under high rainfall, the soil would have likely been saturated and denitrification is promoted under anaerobic conditions.

For the Team Activity:

1. Based on the class's results under managing for a high income (yield), was there only one way to meet this goal? Can you summarize what worked best in general and why?

Expert answer: There was more than one way to meet the goal, but in general, adding a high amount of N fertilizer was the key. N stimulates crop growth, which resulted in higher yield.

2. What was the best way to achieve the goal of increasing soil organic matter stocks and why?

Expert answer: Either planting a perennial crop such as alfalfa, or adding a high amount of fertilizer. Perennial crops tend to have greater root growth, which contributes to increasing soil organic matter. N stimulates crop growth, and thus detrital inputs to the soil organic matter pool.

3. What was the best way to manage for the lowest N in streams and why?

Expert answer: This required a combination of using no-till, a cover crop and a riparian buffer strip. Under no-till, SOM mineralization is reduced, and thus N loss via leaching. Use of a cover crop allows for N uptake before the main crop is planted, and thus takes inorganic N out of the pool of N that is easily leached to the stream. Riparian buffer strips can capture excess N that flows from the field before it reaches the stream.

4. What was the best way to optimize yield and soil organic N while reducing N in Streams and why?

Expert answer: For the same reason as above, it was necessary to use all three N reduction strategies, use of no-till, a cover crop and a riparian buffer strip. Reducing N fertilizer addition for corn also reduced N flow to streams, but the trade-off is that crop yield and detrital inputs were lower. Planting a perennial crop, alfalfa, would increase detrital inputs.

Comments on the Assessment of Student Learning Outcomes:

For the handouts, students receive credit for making an honest attempt for each question, but I do not grade them for correctness. I make the answer keys available after the assignments are due, so that they can correct mistakes on their own. Students are also told that they can expect to see similar material on the exam for the module. That usually motivates students to check the answer keys and ask questions during the review for the exam.

Comments on Formative Evaluation of this Experiment:

To assess students' understanding of principles of element budgets and carbon and nitrogen cycling when I first started using this activity, I evaluated students answers on worksheets before they started the activity (see below). The carbon balance worksheet is based on information from Anderson et al. (1990) and Hartley et al. (2011). I adapted these worksheets for a Canvas quiz format, which enables students to obtain immediate feedback on each question, including explanations for incorrect answers. I did not have IRB approval to use the data from Canvas to formally evaluate student learning, but I used the information as formative assessment.

Description of files:

- Worksheet_The Carbon Balance.docx. Handout for students for this individual activity.
- Carbon balance spreadsheet.xlsx. Accompanies the above worksheet,
- Worksheet_The Carbon Balance_expert answers.docx. Answer sheet for above activity.
- Worksheet_Where is the N.docx. Handout for students for this individual activity.
- Worksheet_Where is the N_expert answers.docx. Answer sheet for above activity.

References Cited:

Anderson, C. W., Sheldon, T. H. and J. Dubay. 1990. The effects of instruction on college nonmajors' conceptions of respiration and photosynthesis. Journal of Research in Science teaching **27**:761-776.

Hartley, L. M., Wilke, B. J., Schramm, J. W., D'Avanzo, C. and C. W. Anderson. 2011. College students' understanding of the carbon cycle: Contrasting principle-based and informal reasoning. BioScience, **61**:65-75.

Comments on Translating the Activity to Other Institutional Scales or Locations:

This activity is translatable to other institutions because it uses a simulation model.