Review of nutrient modeling tools available to assess the impact of small grains on nitrogen and phosphorus

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This document is a summary of research and interviews conducted to identify a model that could assess the potential for on-farm production of small grains to reduce nutrients (nitrogen and phosphorus) leaving farms and entering the Great Lakes Basin watershed. Our investigation led to two conclusions: 1) models do indeed make sense for predicting causal relationships in a case such as small grains and nutrient loading, where the research literature is insufficient to depend principally upon it as guidance; but 2) unfortunately, that dearth of literature also means that currently no model is sufficiently parameterized for small grains to accomplish this goal.

This conclusion informed our decision to not run any of the currently available models, reinforced by recommendations from the diverse experts with whom we consulted, because the resulting data could misrepresent findings based on incomplete or incorrect input data and assumptions. Essentially, these models are not meant to answer the questions we are asking. We did, however, identify opportunities for investment that would bolster existing models to address these inquiries, supporting efforts underway to expand certain models over the coming years in ways that could support these investigations. Those findings are outlined in this summary, along with commentary from experts that assisted in drawing these conclusions.

The primary limitation of most existing models is their lack of small grain inclusion as a cash crop rotation. Furthermore, declining small grain acreage in the region has reduced investment into understanding the role small grains could play as a nutrient reduction strategy, and thus the models are often not calibrated to express this potential. The existing models focus instead on corn and soybean crops and other more commonly deployed conservation practices such as cover cropping. This highlights the need to support research exploring small grain and nutrient interactions within the region's cropping systems, as identified in the accompanying literature review.

Experts Consulted for this Inquiry -this is the list of regional experts we spoke with to ensure thorough review of all available models

- Dr. Eric Booth - Assistant Research Scientist, UW-Madison
- Sarah Carlson - Strategic Initiatives Director, Practical Farmers of Iowa
- Dr. Anna Cates - State Soil Health Specialist, University of Minnesota, Office of Soil Health
- Dr. Laura Christianson - Assistant Professor, Faculty Extension Specialist, University of Illinois
- Dr. Laura Good - Associate Scientist, UW-Madison

- Dr. Natalie Hunt - Teaching Assistant Professor, University of Minnesota
- Dr. Chris Kucharik - Chair, Department of Agronomy, UW-Madison
- Ann Lewandowski - Senior Research and Extension Coordinator, University of Minnesota, Water Resources Center
- Rebecca Power - Director, North Central Region Water Network, UW-Madison
- Dr. Gregg Sanford - Associate Scientist, UW-Madison

Summary of Opportunities & Recommendations

1. Return to the Agro-IBIS model in two years (once it is bolstered with explicit small grain inputs and assumptions specific to the proposed cropping systems for the Upper Midwest region) to run desired simulations
2. Invest in existing N & P state-specific modeling efforts supporting nutrient reduction strategies to ensure small grain representation and accuracy
3. Support field-based research needs, identified in literature review, to refine understanding of small grain nutrient reduction potential to ensure model inputs are sound

Specific cautions on modeling

1. Nitrate concentrations in the soil do not equate to tile drainage leaching losses, so care must be taken when trying to draw conclusions from that data.
2. Modelers sometimes make assumptions that are not aligned with what you are trying to assess. Be sure to trace back to the initial nutrient loss data informing the model to ensure accuracy.
3. Many models meant to quantify these impacts are flawed because they were not built and calibrated to answer the questions you are asking. Many of the existing models are not likely even worth deploying.
4. We are just a couple of years short of being able to run a model that is sophisticated enough to capture the essential relationships we are looking for.

Available models

We conclude that the first two models outlined below (Agro-IBIS and SnapPlus) are the most relevant for this investigation, although shortcomings exist that limit applicability. They are explored in greater depth due to their potential, however, with much more limited summaries offered for additional models with lesser significance for this work.

Agro-IBIS - Integrated BIosphere Simulator

Agro-IBIS simulates the energy, water, carbon, and momentum balance of the soil-vegetation-atmosphere system. It simulates Midwest U.S. natural vegetation (forests, grasslands) and corn, soybean, and wheat agroecosystems, including terrestrial C and N cycling. The model accounts for agricultural management and the effects of environmental stressors on crop development and water balance and uses a 1-hour time step.

- The IBIS model provides a comprehensive simulation of terrestrial processes, and was adapted from IBIS by Kucharik et al., and developed to represent corn, soybean, spring and winter wheat systems in the U.S. Corn Belt region, but its use is expanding to include cover crops and grassland management.

- Inputs include gridded climatic datasets as well as additional relevant terrestrial data such as soil texture. There is a hydrologic model (THMB) attached to Agro-IBIS, which routes surface runoff and drainage to streams and lakes, completing the hydrological aspects of landscape modeling, and illustrates the impact of landscape practices on water bodies
- Example outputs include crop yield, harvest index, root growth, plant N uptake, net N mineralization, evapotranspiration, and soil surface CO_2 flux
- Agro-IBIS does not explicitly parameterize small grains beyond winter and spring wheat.
- Many Midwestern states are working with this model, and there appears to be the greatest potential pathway for small grain incorporation among the other models studied
- References:
    - Model reference page: https://lter.limnology.wisc.edu/project/agro-ibis
    - Publication on model development, Kucharik et al., 2000: https://doi.org/10.1029/1999GB001138
    - Research summary from scientists Eric Booth and Chris Kucharik on the model-estimated relative differences in nitrate loss for several crop rotations across the Corn Belt: http://www.gibbs-lab.com/wp-content/uploads/2019/05/WQintensificationBrief_Booth_v05.pdf

SnapPlus - Soil Nutrient Application

This model, Wisconsin's nutrient management planning software, is designed to help farmers make the best use of their on-farm nutrients (especially phosphorus) and supports informed decision-making for commercial fertilizer purchases. The model calculates potential soil and phosphorus runoff losses on a field-by-field basis, while assisting in the economic planning of manure and fertilizer applications.

- Model (software program) developed for Wisconsin by a team from the University of Wisconsin for the preparation of nutrient management plans
- Model inputs include crop rotations, crop management (e.g. tillage), and soil data
- Model calculations:
    - Crop nutrient (N, P2O5, K2O) recommendations for all fields on a farm, considering legume N and manure nutrient credits consistent with University of Wisconsin recommendations
    - RUSLE2-based soil loss assessment that helps farmers determine whether fields that receive fertilizer or manure applications meet tolerable soil loss (T) requirements
    - Rotational Phosphorus Index value for all fields as required for using the P Index for phosphorus management and a rotational P balance for using soil test P as the criteria for phosphorus management
- SnapPlus-Version 3, is in development, under the direction of Dr. Laura Good
- References: https://snapplus.wisc.edu/

Model	Developer	Geographic applicability	Purpose/ Outputs	Inputs	Reference
Nitrogen Index	USDA-Agricultural Research Service (2019)	Global, local calibration required	Measures estimate of N losses on an annual basis as a result of various agricultural management strategies	Information on soil, crop, manure, fertilizer, irrigation, precipitation, and 'off-site factors'	https://data.nal.usda.gov/dataset/cce-nitrogen-index-tool https://doi.org/10.1016/j.ecoleng.2007.10.006
Agricultural Policy/ Environmental eXtender (APEX)	USDA-ARS	National	Computes flow of sediment, nutrients and pesticides in farms and small watersheds	Soil data, tillage, pesticide and fertilizer use, crop rotation, livestock grazing, weather variables, use of buffer strips, irrigation, and other management (systems) data Integrates SWAT	https://epicapex.tamu.edu/apex/
Nutrient Tracking Tool	TX Institute for Applied Environmental Research, Tarleton State University (2008) – funding from USDA	National – limited testing outside of select project areas	Estimates annual nutrient (N, P) and sediment losses from crop and pasture; includes estimated yield outcomes	APEX 'under the hood' – SSURGO database, PRISM climate database, 30 m DEM Define management scenarios: crop rotation, fertilizer use, conservation practices	https://ntt.tiaer.tarleton.edu/welcomes/new?locale=en
Agricultural Conservation Planning Framework	National Laboratory for Agriculture & Environment (USDA) under Dr. Mark Tomer (2011)	Midwest – HUC 12 watershed scale	Conducts terrain analysis to identify effective and feasible locations for conservation practices	Field boundaries, NASS cropland data, NRCS soils data	https://acpf4watersheds.org/ Note: does not model nutrient movement

Field-to-Market	Consortium of agricultural stakeholders (beta released in 2009)	National	Fieldprint Calculator measures 8 sustainability metrics within a management system	Area of interest, crop rotation, and management information	https://fieldtomarket.org/ Note: measures sustainability, not nutrients
Soil & Water Assessment Tool (SWAT)	USDA (early-1990s)	Globally – requires local calibration	Quantifies effects of management on water resources and non-point source pollution in watersheds and sub-basins; specifically, N, P, and sediment delivery in watersheds	Soil, elevation, weather, and land use and vegetation data as well as calibration parameters for site-specific conditions	https://swat.tamu.edu/
Spreadsheet Tool for Estimating Pollutant Load (STEPL)	EPA (2001)	National	Estimates watershed surface runoff, nutrient loads, and sediment delivery; it also computes the extent of reduction to occur with the implementation of BMPs	Soil data, curve numbers, runoff nutrient concentration, and any additional sediment sources Watershed-level factors: county weather data, land use distribution, livestock population, manure use and septic system information, and Land cover data: percentage of area of a BMP application	https://www.epa.gov/nps/spreadsheet-tool-estimating-pollutant-loads-stepl
Minnesota P Index	University of Minnesota, MN Dept. Ag, MN Pollution Control Agency, NRCS	Minnesota – functionally comparable to SnapPlus	Nutrient management and watershed planning to mediate soil P loss – provides P index	Distance to water, soil test P, erosion, P fertilizer and manure rate and method, tillage type and direction, county, and crop rotation	https://extension.umn.edu/phosphorus-and-potassium/minnesota-phosphorus-index-assessing-risk-

			that represents estimated risk of P loss as a function of management and site factors		phosphorus-loss-cropland
Century/ DayCent Model	Colorado State University	Unknown	Measures C, N, P, K, and S fluxes amongst the soil, atmosphere, and vegetation on a daily time step	Daily air temperature and precipitation, soil texture class, vegetation type, crop rotation, and fertilizer management (timing and amount)	https://www2.nrel.colostate.edu/projects/daycent/
Smartscape	Under development at the Wisconsin Energy Institute (UW-Madison, funded by NIFA), rough model released in 2015	Unknown	Build and evaluate land-use change scenarios - outputs provide a visual evaluation of environmental and economic impacts of land use decisions	To be released	https://gratton.entomology.wisc.edu/smartscape/
Precision Agricultural-Landscape Modeling System (PALMS)	UW-Madison (2005)		Simulates the flow of heat, energy, water, and some chemicals through the air-plant-soil system – outputs include evapotranspiration rates, crop yield, nutrient uptake, runoff, and soil temperature	Topography, weather, crops, and management data	

Additional Resources

- American Farmland Trust - A Guide to Water Quality, Climate, Social, and Economic Outcomes Estimation Tools: Quantifying Outcomes to Accelerate Farm Conservation Practice Adoption
  - https://farmlandinfo.org/publications/guide-to-outcomes-estimation-tools/
  - National scope and not specifically related to models and tools measuring small grain impacts, but a helpful resource to understand other tools and modeling efforts available
  - Includes recommendations for tool developers, tool users, federal agencies, Congress, state agencies, academics, foundations, and corporations
- Minnesota Board of Soil and Water Resources - Water Quality Model, Tool, and Calculator Basics: Reference Guide
  - https://bwsr.state.mn.us/sites/default/files/2019-04/Water_Quality_Model_Tool_Calculator_Basics_Guide.pdf