Nitrogen Management in Agroecosystems: Applying Models and Data in Policy Development

C. Tonitto[1], M.B. David[2], L.E. Drinkwater[1] and C. Li[3]
[1]Department of Horticulture, Cornell University,
[2]Department of Natural Resources and Environmental Sciences, University of Illinois
[3]Complex Systems Research Center, University of New Hampshire

Motivation

• Reactive N added to terrestrial systems from anthropogenic activity is now of similar magnitude to inputs from all natural processes combined.

• Agriculture introduces 86 Tg N of the 140 Tg N annually generated by human sources.

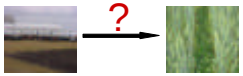
• Current agricultural practices result in a 40-50% loss of applied N.

• 40% of the total U.S. estuarine surface area is classified as severely eutrophied.

• Based on population projections, if global agricultural management adopts the current U.S. paradigm, annual global N fertilizer use would increase from 140 Tg N to 900 Tg N by 2030 (Galloway and Cowling, 2002).

Questions

Do agroecosystems need to be managed as N saturated systems to maintain yield?



Can Haber-Bosch N be replaced with legume-derived N?

Our central hypothesis is that re-coupling C and N cycles will:

1) Increase C flows and soil organic C in agroecosystems;
2) Increase the capacity of the ecosystem to cycle N internally;
3) Reduce N losses; and
4) Reduce the need for surplus additions of N.

Meta-analysis

GOALS:
1) Determine how the use of cover crops influences N loss.
2) Quantify yield effects when Haber-Bosch N is replaced with legume-derived N.
3) Quantify yield effects of non-leguminous cover crops.

Criteria for inclusion in meta-analysis
1) Production of a cash crop every year.
2) Conducted in plots simulating agricultural fields.
3) Cover crop biomass incorporated into the soil or killed before crop planting.
4) N-fixing cover crop: No fertilizer or other N sources added to cover cropped system.
5) Non-N-fixing cover crop: Equivalent N fertilization practices in both treatments.

The **response variable** was calculated as:
$R = \ln(Xe/Xc)$ where
Xc = Control = No cover crop with fertilizer N
Xe = Experimental =
(1) N-fixing cover crop, no fertilizer N
(2) Non-N-fixing cover crop with fertilizer N

RESULTS:
1) Replacing bare fallow with a non-legume cover crop reduces nitrate leaching by 70% relative to conventional management. Fields fertilized with legume-derived N averaged a 40% reduction in nitrate leaching (**Figure 1**.)
2) Following good legume establishment, cash crop yield in legume-fertilized systems did not significantly differ from that of Haber-Bosch N fertilized systems (**Figure 2**).

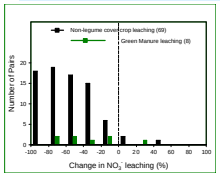


Figure 1. Distribution of number of pairs showing the effect of cover crops on nitrate leaching in deciles of percent change from the control. Mean values and 95% confidence intervals of the back-transformed response ratios are shown in the legend (number of comparisons in parentheses).

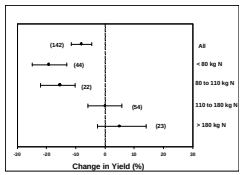


Figure 2. Effect of legume cover crops on cash crop yields in units of percent change from the control grouped by legume N input rate. Mean values and 95% confidence intervals of the back-transformed response ratios are shown (number of comparisons in parentheses).

DNDC Modeling

GOALS:
1) Calibrate and validate the Denitrification-Decomposition (DNDC) model for tile-drained agroecosystems of Illinois. Assess ability of DNDC to reproduce measured water and nitrate leaching. Assess temporal resolution for which the model is accurate. Assess model sensitivity to parameter variation.
2) Compare DNDC predictions of yield and nitrate leaching under diversified relative to conventional corn-soybean rotations in Illinois tile-drained regions.
3) Compare DNDC predictions of N trace gas emissions under diversified relative to conventional management.

Model System:
1) Embarras River Watershed in east-central Illinois.
2) Conventional Management:
corn-soybean, winter bare fallow, 190 kg N ha^{-1}
N applied 50% fall, 50% spring for model calibration and validation.
N applied 100% spring for comparison with diversified rotations.
Daily field measurements of climate, water and nitrate leaching available for model calibration and validation.
3) Diversified systems:
corn-cereal rye-soybean-cereal rye (N input = fertilizer)
corn-soybean-wheat (N input = fertilizer)
corn-cereal rye-soybean-wheat (N input = fertilizer)
corn-soybean-wheat-red clover (N input = N-fixation)
corn-cereal rye-soybean-wheat-red clover (N input = N-fixation)

Statistical Criteria:
Model applicability to the Illinois system was tested using bias and autocorrelation metrics.
The statistical significance of model predictions relative to field measurements was tested using modeling efficiency, Theil's inequality, and the correlation coefficient.

RESULTS:
1) Diversified rotations maintain yield comparable to the conventional system (**Table 1**), though some diversified systems showed a small reduction in yield.
2) Adding a winter cover crop to a conventional corn-soybean rotation reduced NO_3^- leaching by 35% (**Table 2, Figure 3A**).
3) Rotations based on N-fixation exhibited NO_3^- leaching reductions ranging from 35-45% and N_2O flux reductions of 20% relative to conventional management (**Table 2, Figure 3A,C**).
3) N_2 flux was comparable across rotations tested (**Table 2, Figure 3B**).
4) N_2 and N_2O flux was a similar magnitude to N loss via nitrate leaching (**Table 2**).

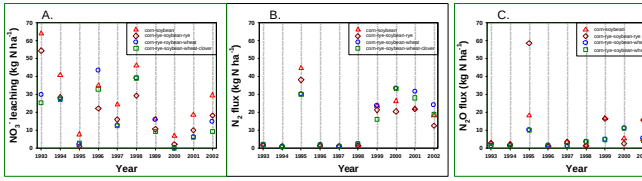
Table 1. Average annual conventional crop yield and percent deviation of yield in diversified systems over a 10 year simulation. Data from the top 4 parameter sets are presented.

	Yield (kg C ha^{-1})	
Conventional	**corn**	**soy**
corn-fallow-soybean-fallow	**3,890**	**1,550**
Diversified	**% deviation from conventional**	
corn-rye-soybean-rye	**-8.3**	**-7.8**
corn-soybean-wheat-fallow	**4.1**	**1.2**
corn-rye-soybean-wheat-fallow	**4.1**	**-3.7**
corn-soybean-wheat-legume	**-9.9**	**-0.5**
corn-rye-soybean-wheat-legume	**-10.5**	**-4.6**

Table 2. Mean cumulative N flux from NO_3^- leaching, N trace gases, N-fixation, Gross N mineralization (Gross min), and Net N mineralization (Net min) over a 10 year simulation. Table values report the mean cumulative fluxes predicted using the top 4 parameter sets.

Rotation	Mean cumulative N flux (kg N ha^{-1})							
	NO_3	N_2O	NO	N_2	NH_3	N fixation	Gross min	Net min
corn-fallow-soybean-fallow	289	59	28	141	7	772	2373	773
corn-rye-soybean-rye	193	106	30	121	7	711	2459	782
corn-soybean-wheat	282	55	23	153	5	615	2247	731
corn-rye-soybean-wheat	254	53	23	138	5	584	2285	742
corn-soybean-wheat-clover	192	47	21	151	1	1334	3467	1407
corn-rye-soybean-wheat-clover	165	45	21	134	1	1307	3505	1405

Figure 3. Modeled annual trends in the flux of NO_3^- (Fig 3A), N_2 (Fig 3B), and N_2O (Fig 3C). Data are presented for the conventional corn-soybean rotation with winter bare fallows, compared to diversified rotations including: 1) corn-cereal rye-soybean-cereal rye 2) corn-cereal rye-soybean-wheat, and 3) corn-cereal rye-soybean-wheat-red clover.



Conclusions

1) A quantitative review of the literature using meta-analysis suggests:
Yield losses were minimal with non-N-fixing cover crops; reductions in NO_3^- leaching averaged 70%.
Legume-based rotations averaged a 12% yield reduction overall and 40% less NO_3^- leaching.
Legume-based rotations were successful on a yield basis when biomass N was ≥110 kg ha^{-1}.
2) Application of the DNDC model suggests diversified rotations reduce N loss as NO_3^- and N_2O.
3) Field and modeling studies suggest increased coupling of C and N cycles enhances ecosystem retention of biologically available N.

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