Optimizing Nitrogen Rates in the Midwestern United States for Maximum Ecosystem Value

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Purpose: Optimize the tradeoff between corn yield and water quality across utilty preferences as a function of synthetic nitrogen input and biophysical context.

Introduction

High corn production requires high nitrogen (N) fertilization, which carries costs to environmental services such as water quality. Therefore, a tradeoff exists between the production of both corn yield and water quality. We employ the GWAVA-S and CERES-Maize models to investigate the nature of this tradeoff.

Study Area

The study region covers 31 counties in southern Minnesota and northern Iowa and lies at the heart of the U.S. Corn Belt.

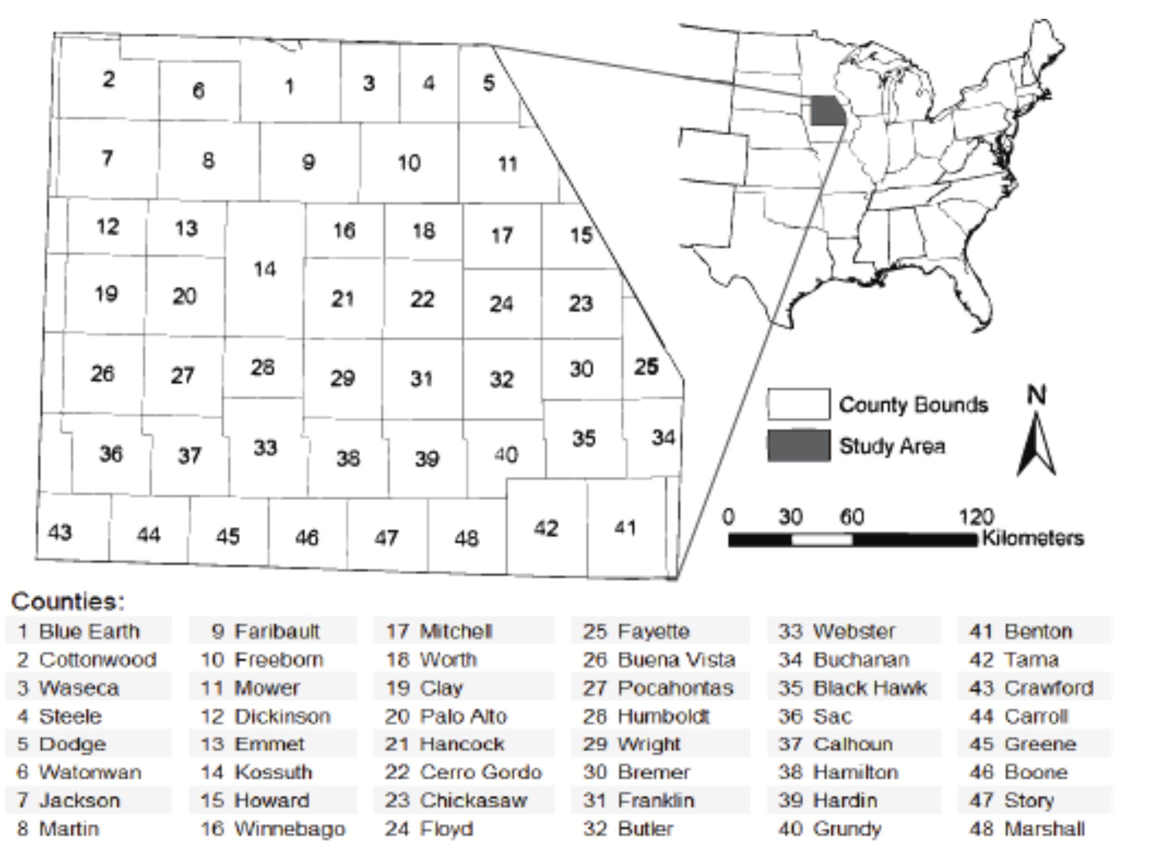

Fig. 1

Land Cover (2012)

In 1975, corn covered 77.5 million acres in the United States (USDA-SRS 1975), and by 2012, corn's planted area had grown to a record high of roughly 97 million acres (NASS 2012).

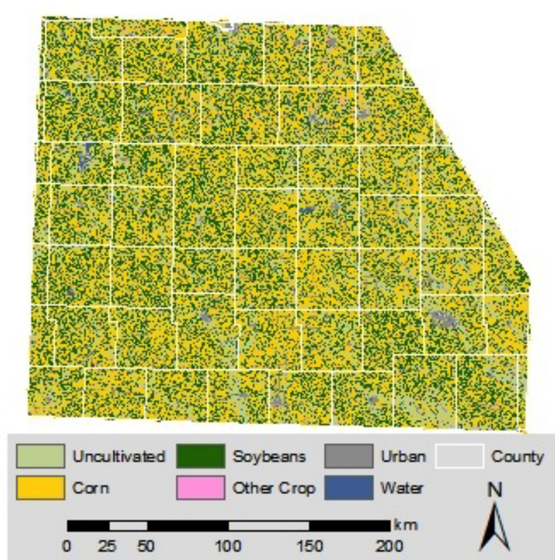

Fig. 2

Methods

We used ArcGIS 10.0 (ESRI 2010) to perform spatial operations and R 2.14.1 for all other calculations and plotting using the packages base (R Development Core Team 2011) data.table (Dowle et al. 2013), ggplot2 (Wickham 2009), plyr (Wickham 2011), and sqldf (Grothendieck 2012).

Modeling Water Quality

-- Ground WAter Vulnerability Assessment (GWAVA-S) model (Nolan and Hitt, 2006) and STATSGO2 Database

-- GWAVA-S is divided into three sections: N input, Transportation (Ti), and Attenuation (Ai)

$$c_{gwi} = \left(\sum_{n=1}^{N} \beta_n X_{ni} \right) \cdot T_i \cdot A_i + \varepsilon_i \qquad \text{Eq.1}$$

-- Ti and Ai are exponential functions calculated for each grid cell (i) from input parameters that in the study region consist of soil properties based on pre-compiled layers

-- Ti and Ai were calculated in ArcGIS 10.0

Modeling Corn Grain Yield

--Crop Environment Resource Synthesis (CERES) maize model housed in the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al. 2003)

-- Time-step model that simulates corn crop growth, development and yield as a function of soil-plant-atmosphere dynamics

-- Ran model across N application rates (anhydrous ammonia) of 0 kg ha-1 and 75 – 350 kg ha-1 at 25 kg intervals for each combination of soil texture, soil depth, variety, and N rate.

--Outputs were then exported to R and quadratic-linear regressions of yield as a function of N application rate were estimated for each soil texture aggregating soil depth and variety.

Optimization Procedure

-- All model outputs were integrated in R for optimization.

-- Data was aggregated by both county and study area and plotted as a scatter plot to produce a non-optimized production frontier

-- Ideal N application rates were estimated by selecting the higher of the two N rates whose slope closest matched a given utility preference

-- Utilities ranged from 0.05 to 50 on an exponential scale

Results

Study Area Wide

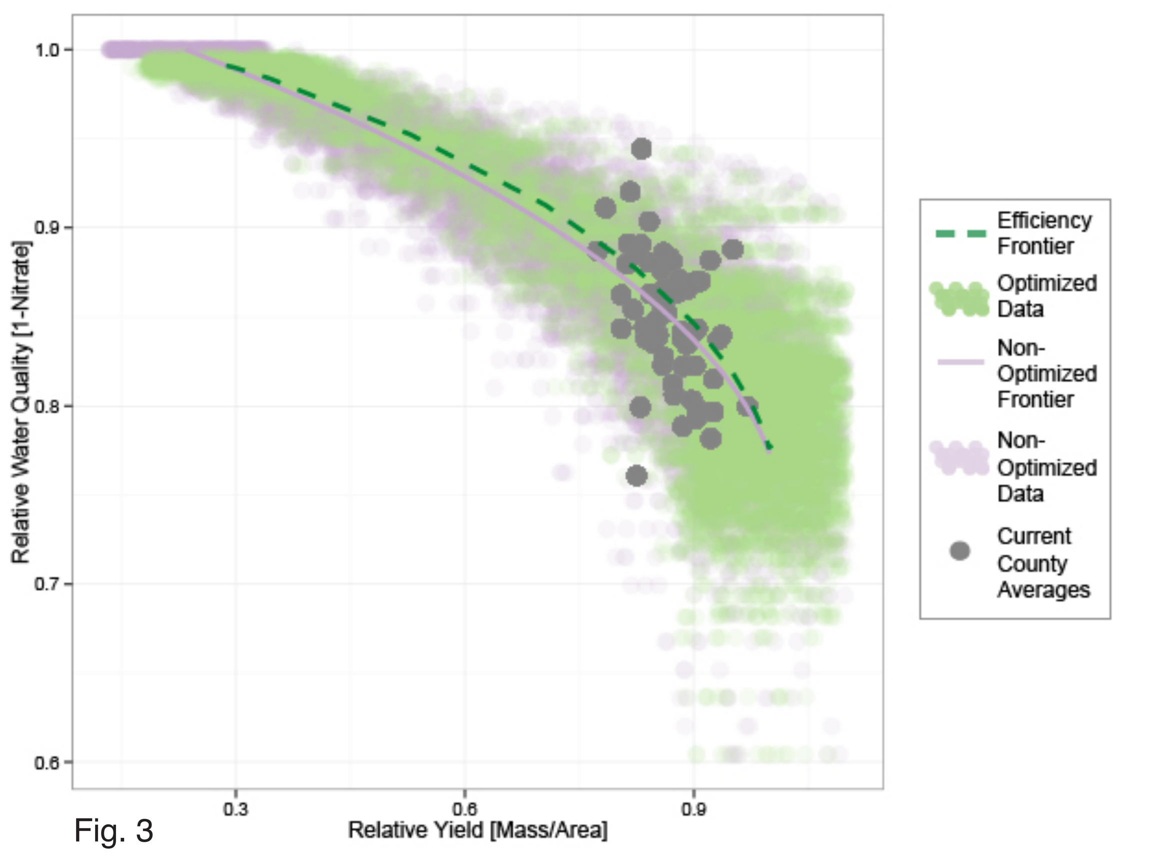

Fig. 3

Selected County Level Results

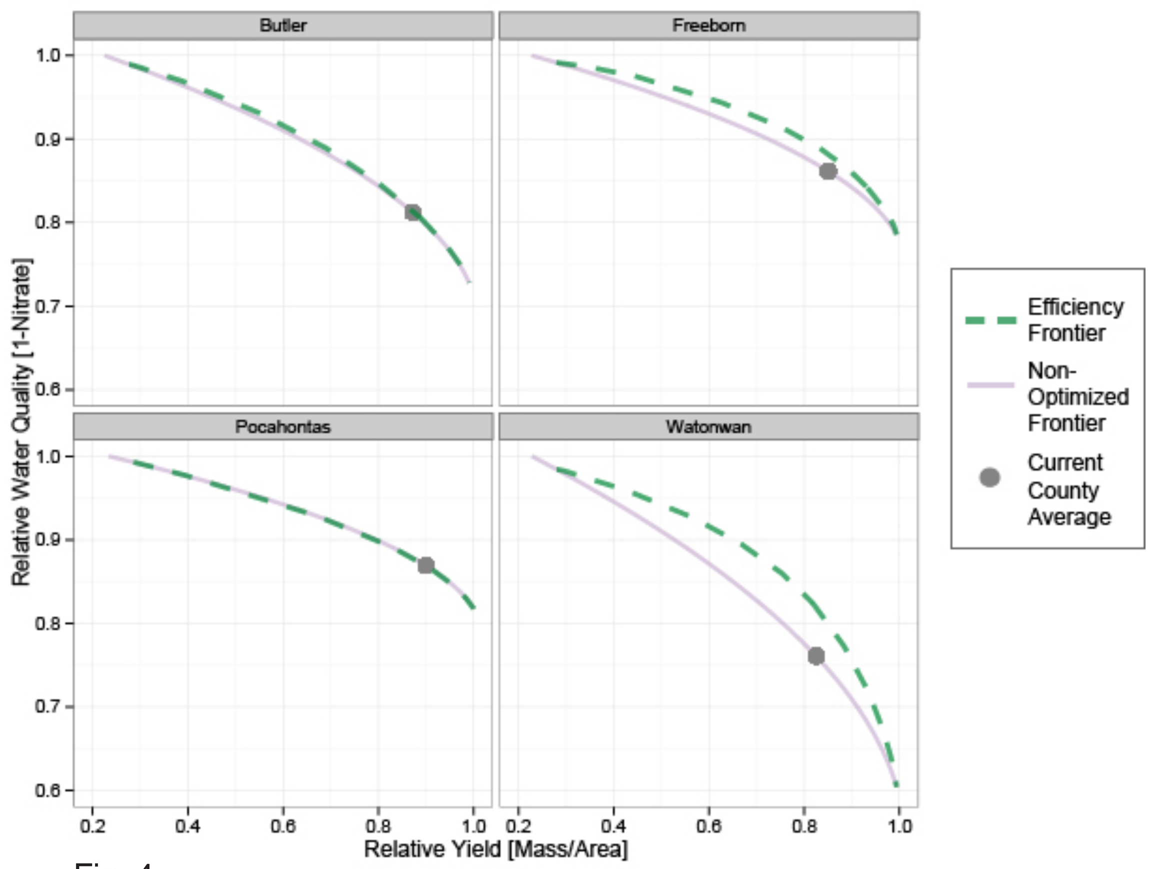

Fig. 4

Optimized Synthetic N Usage Study Area Wide

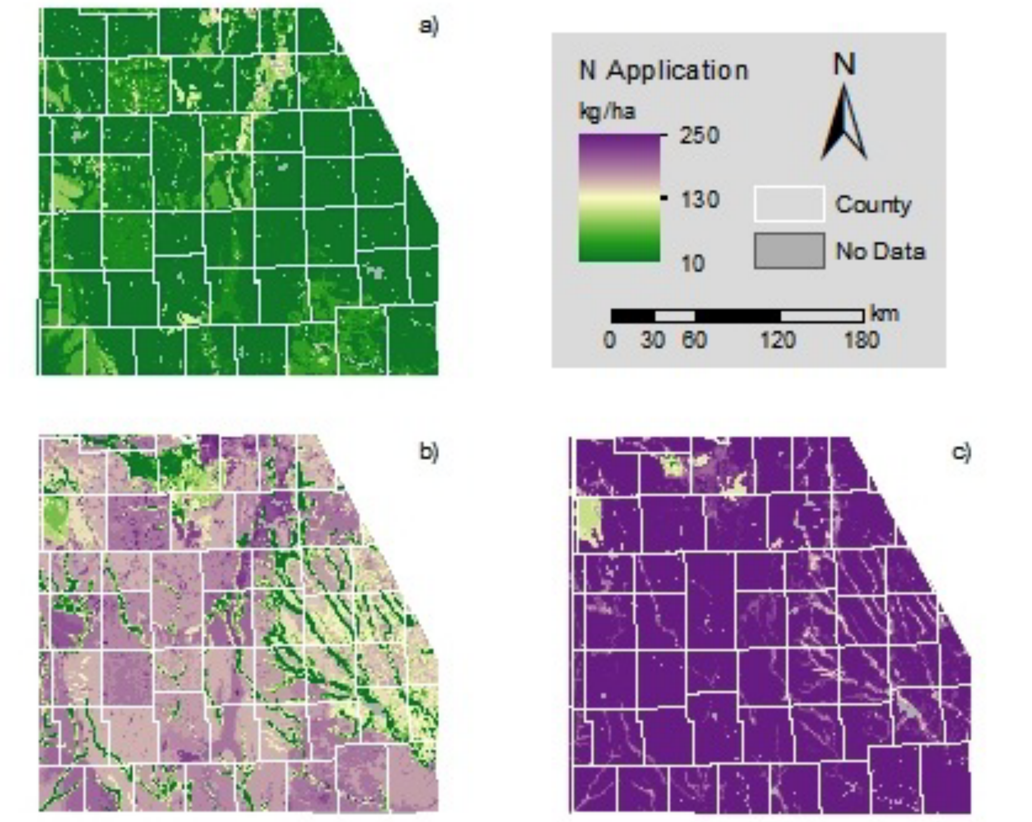

Fig. 5

Conclusions

-- Results demonstrate a clear study wide efficiency frontier that differs from the study area average

-- At the individual county level, it becomes apparent that the scale of analysis and the context of analysis greatly impact the nature of the tradeoffs and the potential for gains through optimization

-- Counties such as Watonwan County seemingly have the opportunity for great gains without having to sacrifice either water quality or yield

-- Pocahontas County appears to already be at the edge of efficiency in the context of our modeling process

-- Soil texture dramatically impacts the nature of the tradeoff between water quality and yield

-- Contrasting Watonwan County and Pocahontas County highlights the importance of biophysical constraints on the production of ecosystem services

-- New tools are needed that embrace biophysical reality and simultaneously acknowledge divergent stakeholder preferences

Citations

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