Nitrogen surplus: An environmental performance indicator for sustainable food supply chains

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Abstract
Nitrogen pollution and its negative impacts on human and environmental health are embedded in commodities traded domestically and internationally; we focus on grain because of its importance as a feedstock for food, feed and fuel. Food supply chain companies, in particular retailers and food processors, can play a catalytic role in reducing that burden through sustainable sourcing of grain and grain-derived products. We describe how such sourcing commitments might work to reduce N losses and how progress towards them can be tracked using a simple, robust and scalable indicator: N surplus. Using model simulations and empirical data on U.S. maize production, we show that N surplus, the difference between annual N inputs (fertilizer, manure, biological nitrogen fixation) and grain N outputs, is strongly related to N losses at field to regional scales. This analysis suggests that supply chain companies can set performance goals related to reductions in N surplus, which in turn could translate into large improvements in environmental outcomes. Recognizing that individual producers will need guidance and motivation on how to reduce N surplus, we present a conceptual model for using farmer-derived data in a social learning context to identify combinations of management practices that most effectively reduce N losses and improve crop yield or profit.

Key Words
Nitrogen pollution, food supply chain, nitrogen surplus, environmental benchmark, nitrogen offsets.

Introduction
Recent studies have documented the substantial role of international trade in agricultural products on the global reactive nitrogen (N_r) footprint (Lassaletta et al, 2014; Oita et al, 2016) and human and environmental health (e.g. Paulot and Jacob, 2014). Food supply chain companies are uniquely positioned to help reduce this N_r burden by creating a demand signal for sustainable commodities. Market demand from retailers such as Walmart can catalyze change along the supply chain, from food processors to agricultural producers, and across national borders. Because the N_r footprint of many commodities is dominated by the production of grains (maize, rice and wheat), a market signal for grain produced with reduced N_r losses is potentially capable of driving change across approximately 100 million ha of cropland in the U.S. alone. The challenge is how to translate this concept into a workable framework that is simple for companies to adopt and for producers to implement. Our paper presents such a framework, based on the use of N surplus (N inputs [fertilizer, manure and biological nitrogen fixation] minus N outputs [N removed in harvested grain and straw/stover removal]) as an environmental performance indicator. The focus on N surplus reflects our interest in environmental outcomes (reduced N_r losses), although we recognize that in working with producers it will be more effective to frame conversations in terms of related metrics, e.g. N fertilizer use efficiency (NUE). However, estimating NUE requires detailed measurements to distinguish between crop N uptake from soil N reserves versus uptake from applied N (Cassman et al. 2002). Hence our focus on N surplus, which is much more straightforward to estimate.

Description of the framework
Consumer demand has led to dramatic growth in company commitments to reduce their environmental footprints. A number of companies, including Walmart, General Mills and PepsiCo have made commitments to reduce either greenhouse gas emissions (especially nitrous oxide [N_2O]) or water quality impacts (especially nitrate loads) in their supply chains. Focusing on only one type of nitrogen loss creates the risk of pollution swapping, whereby efforts to reduce nitrate leaching may increase gaseous losses, and vice versa. For this reason, we suggest that companies consider developing commitments that address all forms of N_r.

Accountability: need for a simple, robust and scalable performance indicator
To date, corporate efforts to improve sustainability have advocated for the adoption of suites of conservation practices and then attempted to model the environmental outcomes of those practices. However, there is little consensus in the peer-reviewed literature on the impact of practices such as fertilizer stabilizers, conservation tillage, and cover crops on N_r losses, and few models which have been calibrated and validated across a broad range of crops, geographies and practices. For this reason we suggest the need for a simple, robust and scalable indicator of environmental performance. Ideally, such an indicator would be: (i) based on field-level data easily collected by participating producers, (ii) directly relate to changes in environmental outcomes, (iii) meaningful to producers in helping them improve overall farm productivity and profitability, and (iv) capable of being aggregated across thousands of fields in a sourcing region. We suggest that N surplus is such an indicator.

N surplus as an environmental performance indicator
Beginning with van Groenigen et al (2010), a number of authors have identified a relationship between N surplus and yield-scaled N losses. We have compiled and analysed a database of yield-scaled N_2O emissions, yield-scaled nitrate leaching, and N surplus derived from empirical field studies on maize production in the U.S. Corn Belt. For example, data reported by Venterea and Coulter (2015) were used to obtain a strong curvilinear relationship between yield-scaled N_2O and N surplus at one well-studied site (Fig. 1a). A similar strong relationship was also reported by Venterea et al (2016). In a parallel effort we are conducting simulations of maize production and associated N losses using Adapt-N, a Web-based dynamic simulation model (Melkonian et al 2008). Results of 8100 simulations of total N losses associated with a number of N management scenarios across multiple locations and soil types in the Corn Belt are shown in Figure 1b (Sela et al 2016). Model simulations support and extend the inference from the empirical data that there is a strong positive relationship between N surplus and yield-scaled N losses and further suggest a breakpoint at an N surplus value of about 50 kg/ha above which N losses rise dramatically. While our analysis is focused at the field scale, others have documented a relationship between N surplus and N losses (especially nitrate leaching losses) at regional scale (David et al 2010), suggesting that N surplus can be used as an indicator of environmental performance across a variety of scales.

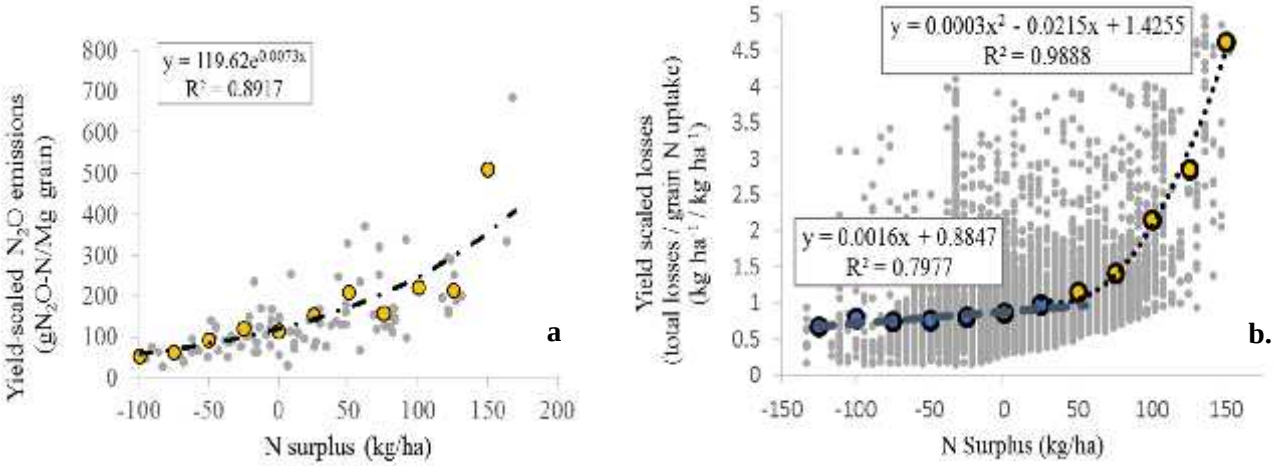

Figure 1a. Empirical relationship between yield-scaled N_2O losses and N surplus for maize in Minnesota, USA, derived from data reported by Venterea and Coulter (2015). Figure 1b. Results of 8100 simulations of N management scenarios for maize production in the Corn Belt of the USA, showing the relationship between yield-scaled total N losses and N surplus. Note the similarity of the relationship between yield-scaled N losses and N surplus in both figures and the suggestion in both of a breakpoint at approximately 50 kg/ha.

Putting it all together: a nitrogen surplus framework to improve nitrogen management in food supply chains
Based on Figures 1a and 1b, we see opportunities for retailers and food processors to reduce total N_r losses associated with the grain and grain-derived products they purchase. Such commitments could take the form of an agreement to preferentially purchase products produced with low values of N surplus. It is notable that Unilever's Sustainable Agriculture Code already requires its suppliers to report N surplus each year, and expects N surplus levels to decrease over time (Unilever 2015). We suggest that other food processors and retailers could make similar and even stronger commitments by setting performance goals related to reductions in N surplus. Further upstream in the supply chain, this demand signal could lead to preferential purchasing by grain aggregators and in turn to incentives for farmers and farm service providers to create a

supply of sustainably-produced grain across tens of thousands of acres of cropland in a sourcing region (Figure 2). Key to success is development of a robust reporting framework for N surplus in which food companies would report on the N surplus performance of their suppliers (aggregators). Aggregators in turn would compile information on N inputs and grain N outputs from a geographically-defined set of producers, and crop producers would be helped to minimize N inputs and/or maximize crop N uptake by working with farm service providers.

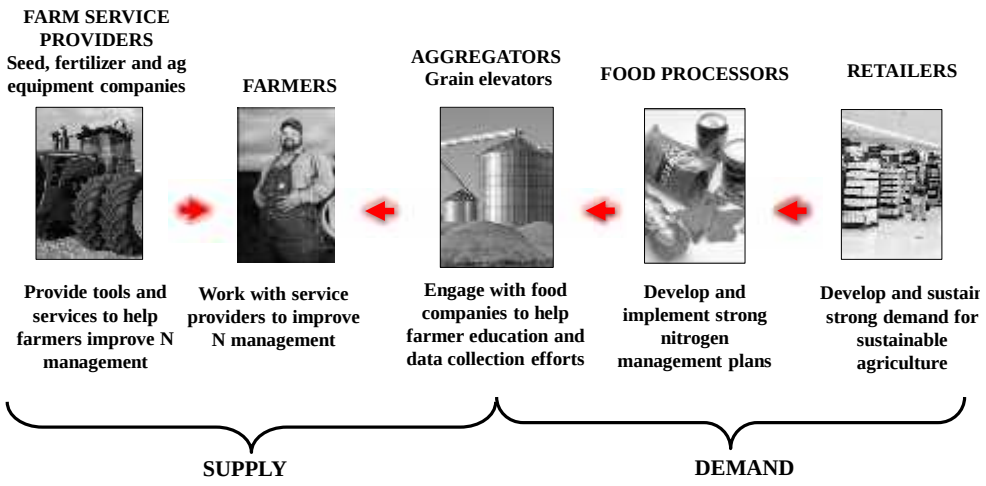

Figure 2. A conceptual model showing how demand by retailers for sustainably-sourced products could drive change upstream along the supply chain, ultimately encouraging farmers to reduce N surplus.

Setting performance targets

We are confident that N surplus is a directionally correct indicator of N losses, such that reductions in N surplus will lead to reductions in N losses when aggregated across thousands of producers or watersheds. Based on the preliminary work shown in Figures 1a and 1b, additional analyses are in progress to better define the nature of the relationship between N surplus and yield-scaled N losses for specific agro-ecologic regions within the Corn Belt. If we are successful, such a relationship would allow food supply chain actors to quantify the environmental outcomes of their efforts to improve N management in grain production. Companies could, for example, choose to set a target such as a 20% reduction in regionally-aggregated N surplus from a specified baseline, or they could establish a cropping-system specific level of N surplus which all participating producers would be asked to achieve and verify.

Helping producers reduce N surplus

We note that there are some general guidelines which can be used to help producers reduce N surplus. For example, crop rotations (especially those rotations which include legumes) can reduce N surplus over the duration of the rotation, and practices such as cover crops which recycle N within the crop field are also likely to be beneficial. For mixed (crop-livestock) farms, substitution of on-farm manure for synthetic fertilizer will likewise reduce N surplus.

The concept of reducing N surplus may also be framed around the productivity and economic benefits of improving NUE. Identifying the best management practices to improve NUE for particular crops, cropping systems, soil types, and climates may be best determined through an adaptive learning process which engages producers. We suggest adapting the performance benchmarking approach described by Grassini et al (2011) to help groups of producers identify the most effective practices for improving NUE (specifically NFFP, kg grain/kg applied) on their farms. Figure 3 below shows, for an imaginary cohort of producers in a single agro-ecological region with relatively uniform climate and soil conditions, a hypothetical plot of crop yield against N input data to illustrate the potential of this approach. Clearly, some producers (shown in blue) achieve greater NUE than others (shown in yellow), which also means higher yields and greater return from investment in fertilizer. Sharing these data in a social learning setting such as a farmer network (Rosman, 2015) will both identify those practices that lead to better crop (and environmental) outcomes and facilitate broader adoption of these practices.

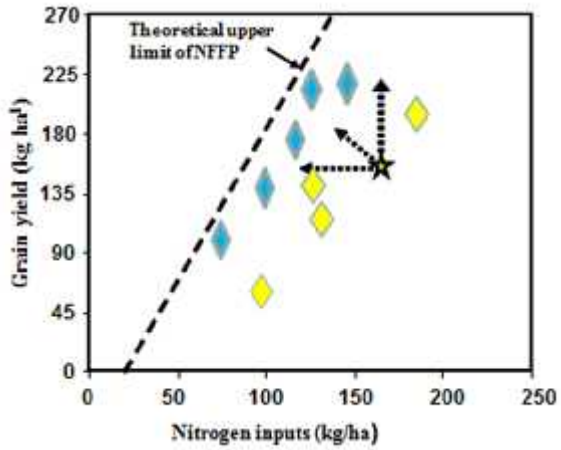

Figure 3. The graph shows a hypothetical set of data from a cohort of farmers in a single agro-ecoregion. High-performing farmers (in blue) lie closer to the theoretical upper limit of NFFP; low-performing farmers (in yellow) may be able to improve NFFP as shown by the arrows. Modified from Grassini et al 2011.

Conclusion

Food supply chain demand for sustainably-produced products could drive the adoption of improved N management practices at scale across sustainable sourcing regions. Company commitments to reduce aggregated N surplus at regional scale could encourage farmers to improve nutrient use efficiency while reducing the environmental impacts of grain production.

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