IMPROVED NITROGEN MANAGEMENT FOR THE FOOD INDUSTRY SUPPLY CHAIN

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ABSTRACT

A project is being led by the International Plant Nutrition Institute (IPNI) and The Fertilizer Institute (TFI), with cooperation by Fertilizers Canada (FC), to help strengthen the science underpinning the Field to Market Alliance for Sustainable Agriculture Fieldprint Calculator (FPC) and its field-scale greenhouse gas (GHG) emissions estimates. Cooperating Land Grant University nitrogen (N) management scientists and USDA NRCS and ARS nitrous oxide (N_2O) emission scientists were invited to work together in developing science consensus-based suites of 4R sensitive N management practices. Seven corn, soybean, and wheat system 3-tiered (*Basic, Intermediate, Advanced*) 4R-N- management frameworks were developed to help guide farmers and crop advisers toward increased N use efficiency, greater crop productivity, and reduced N_2O emissions. This work has successfully brought together cropping system N management scientists and N_2O emission scientists from the U.S. and Canada, and it is expected to broaden the science base and approaches used in developing and adapting cropping system sustainability metrics used within the Field to Market FPC and by members of the U.S. food industry supply chain.

INTRODUCTION

At the April 2014 Walmart Sustainable Product Expo, several companies followed Walmart's lead and pledged major reductions in their agricultural and food product greenhouse gas (GHG) emissions (http://news.walmart.com/walmart-sustainable-product-expo-supplier-commitments):

- Campbell Soup Company
- Cargill
- Dairy Farmers of America
- General Mills
- Monsanto
- Kellogg Company
- Pepsico

At that Sustainable Product Expo, Walmart stated: "In the area of fertilizer management, Walmart last year set a goal of optimizing 14 million acres of farmland with the potential to reduce seven million metric tons of GHGs. Combined with progress already made, the new pledges announced today will help advance that goal by optimizing an estimated 10 million acres and eliminating 8.5 million metric tons of GHGs." Over half of these Walmart-partnering food supply chain industries are influential members of the Field to Market Alliance for Sustainable Agriculture.

It is not surprising that these and other food supply chain companies have taken interest in nutrient management (*often on fertilizer use reduction*), since they recognize that fertilizer production and use account for a large portion of cropland GHG emissions; especially nitrous oxide (N_2O). Current USDA and EPA GHG inventory estimates indicate that N_2O represents 5% of the U.S. annual carbon dioxide equivalent (CO_2-e) GHG emissions (**Figure 1**), yet agriculture accounts for 2/3 to 3/4 of those N_2O emissions; primarily soil management and crop production (*that includes fertilizer and manure use*) (http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html). In spite of the fact that N_2O represents only a small portion of the total U.S. CO_2-e GHG emissions, many companies and environmental interests recognize that modest investments in reductions of N_2O emissions can greatly reduce CO_2-e GHG emissions associated with agricultural field crop and forage production. Increasingly, these companies and others understand that the global warming potential of N_2O is roughly 300 times that of an equivalent mass of carbon dioxide (CO_2), and that N_2O is also a concern as a major atmospheric ozone depleting substance (UNEP, 2013).

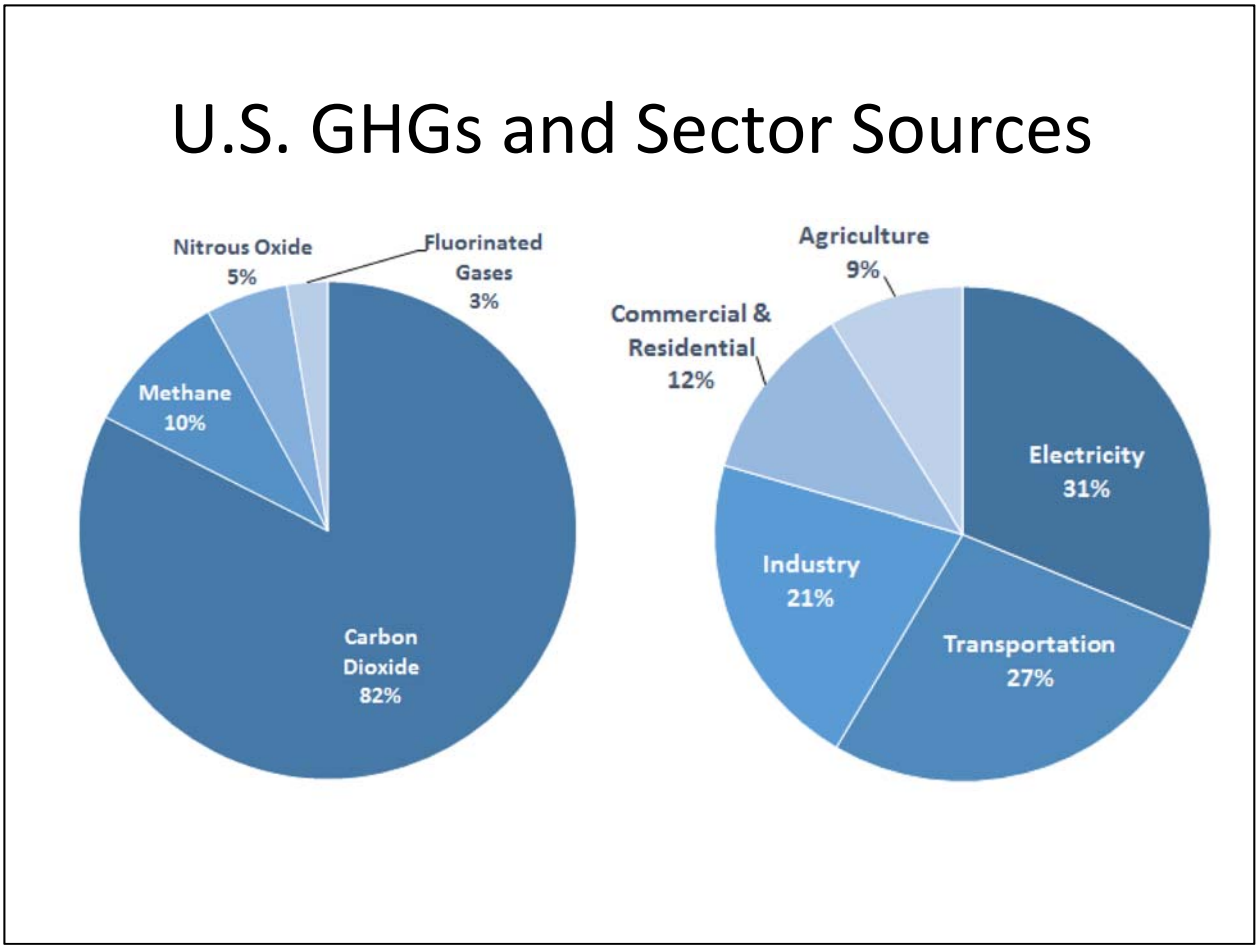

Figure 1 – U.S. greenhouse gases emitted in 2013 and sources of those total estimated carbon dioxide-equivalent greenhouse gas emissions (USEPA, 2015).

The Field to Market Alliance for Sustainable Agriculture, with 75 member organizations, (https://www.fieldtomarket.org/) developed a Fieldprint Calculator (FPC; https://www.fieldtomarket.org/fieldprint-calculator/) to estimate national-level (*reports issued in*

2009 and 2012) and individual field sustainability indicators, for the following leading U.S. agricultural field crops: corn, soybean, wheat, cotton, rice, and potatoes. The sustainability indicators are based on the following key sustainability metrics:

- Land Use
- Conservation
- Soil Carbon
- Irrigation Water Use
- Water Quality
- Energy Use
- Greenhouse Gas (GHG) Emissions

Several Field to Market members are conducting pilot programs and FPC projects (https://www.fieldtomarket.org/fieldprinting-projects/) to become familiar with the FPC, and they are encouraging their supplying farmers to use the FPC. Several of those companies wish to use the aggregated FPC GHG results of their farmer partners to upscale those supply chain results, to help reduce their company and food product GHG footprints; and meet their sustainability goals and commitments.

These seven (7) sustainability metrics in the FPC, mentioned above, are subject to update and improvement on about a five-year rotating interval. The GHG metric is under update consideration this year: 2015. Currently, the Field to Market Fieldprint Calculator (FPC) GHG N_2O estimation (*developed in 2009-2010*) relies on a simple, nitrogen (N)-rate-dependent multiplier to estimate cropland fertilizer N use impacts on N_2O emissions; with some emission reduction consideration given for nitrification inhibitors. The N rate multiplier of 1.4 is used to estimate (*erring on the side of over-estimation*) the combined direct and indirect field N_2O emissions, based on Intergovernmental Panel on Climate Change (IPCC) guidance (IPCC, 2006). Unfortunately, this IPCC-based coefficient (*actually intended by IPCC only as a national scale estimator*) gives no consideration to the source, time, or place of N application(s) in the N_2O emissions estimates within the FPC. However, estimates of the imbedded energy and GHG emissions associated with the production of several major fertilizers are included in the current FPC, and are based on estimated values within the public Argonne National Lab's GREET model, version 1.8d (Wang et al., 2007).

MATERIALS AND METHODS

The International Plant Nutrition Institute (IPNI) and The Fertilizer Institute (TFI) began an industry-sponsored and supported project (*i.e. no financial support from Field to Market*) that was proposed to, and accepted by, leaders and members of the Field to Market metrics workgroup in early 2015. The FPC GHG N_2O emissions estimator project goals are to overview and enlist current agronomic and soil science N management knowledge, which may allow modifications of the Field to Market FPC N_2O estimator; ultimately enabling the FPC to be more inclusive of all 4Rs of Nutrient Stewardship (right source, rate, time and place of application). It was/is anticipated that the project will provide fertilizer N-rate N_2O emission reduction modifiers to Field to Market (in Excel format), for integration into the FPC fertilizer N-related N_2O emission algorithms by early to mid-2016.

Because there is considerable N_2O emissions research knowledge in Canada, and to ensure that the science and products of the U.S. Field to Market FPC GHG project are not in conflict with N_2O emissions science in Canada, Fertilizers Canada (FC; *formerly known as the Canadian Fertilizer Institute*) was approached and agreed to work with IPNI and TFI. Fertilizers Canada

agreed to support travel and project participation by a few N_2O research scientists from Canada. Dr. Cliff Snyder-IPNI, Lara Moody-TFI, and Clyde Graham-FC form the project Steering Committee, and coordinate communications and workshop facilitation through assistance by Karen Haugen-Kozyra and Matt Sutton-Vermeulen) with The Prasino Group. The Prasino Group was chosen to assist in the transparent, science-based, science-vetting process of the project because of their prior experiences with N_2O and CO_2 emission reduction projects, protocols, and science, and for their knowledge of International Organization for Standardization (ISO) standards.

IPNI and TFI identified leading cropping system N management and N_2O emission scientists from within the USDA and leading agricultural universities, and invited them to a science coordination and consensus-building workshop in March 2015. Two scientists from Canada and more than 25 N scientists from the U.S. were invited, and ultimately 15 scientists who did not have prior commitments, accepted and attended the March 2015 workshop in Chicago, IL (**Figure 2**). Each N scientist who was approached expressed sincere interest in the project and workshop. The N science workshop participants received a briefing document (i.e. Science Discussion Document) representing a current literature overview, some recently published N_2O mitigation papers (e.g. Decock, 2014; Snyder et al; 2014), and the project overview and objectives.

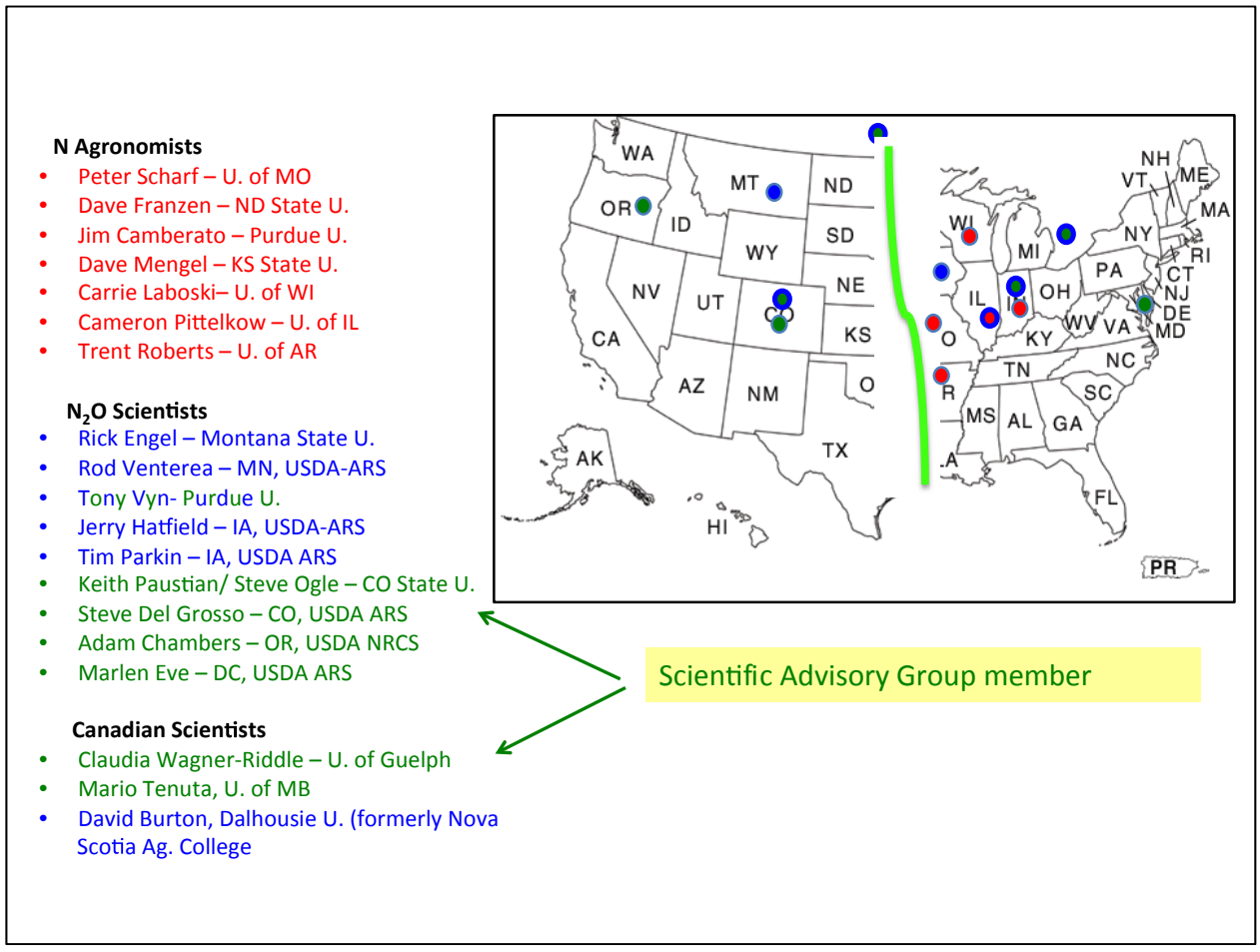

Figure 2 – Invited scientists who participated in the IPNI and TFI-led nitrogen (N) management and N_2O emissions workshop, March 2015.Workshop

This IPNI-TFI led FPC GHG project and the science-vetting processes are receiving oversight by a Science Advisory Group (SAG), and regular observance by the Science and Research Director (*Allison Thomson*) and the President (*Rod Snyder*) of Field to Market. Members of the SAG include: N management and N_2O emission scientists from: USDA ARS- *Dr. Steve Del Grosso*, USDA NRCS – *Dr. Adam Cha*mbers, and the USDA ARS (previously with Office of the Chief Scientist-Climate Change) –*Dr. Marlen Eve*; Colorado State University- *Dr. Keith Paustian (Dr. Steve Ogle substitute)*; Purdue University – *Dr. Tony Vyn*; and scientists with the University of Manitoba –*Dr. Mario Tenuta* and the University of Guelph- *Dr. Claudia Wagner-Riddle* in Canada. Although this project is considered strictly a U.S. project, we sought to include relevant cropping system N management science input from Canada to avoid the potential for N science and interpretation "boundaries" between the two countries. In addition, we understand that there is the possibility that Field to Market will be expanding into Canada.

Besides bringing together and establishing a network of cropping system N management and N_2O emission experts, the major objective of the science coordination workshop held in March 2015 was to develop 4R-tiered (**Basic, Intermediate, Advanced**) N management frameworks for seven (7) regionally-sensitive corn-soybean and wheat cropping systems in the U.S, that reflect improved N use efficiency and effectiveness. It was anticipated that the tiered-4R-N management frameworks would enable the invited N science workshop participants to assign modifiers (i.e., coefficients) to the FPC N-rate dependent estimates of N_2O emissions, to afford farmers, their advisers, and the industry the opportunity to continuously improve their sustainable 4R N management practices, while reducing crop agriculture N_2O emissions; without sacrificing crop yields or soil productivity.

Drafts *("strawdogs")* of tiered-4R-N management frameworks (3-tiers: **Basic, Intermediate, Advanced**), which represent combinations or suites of 4R practices that are expected to achieve incremental improvements in N use efficiency and effectiveness, were developed by IPNI scientists in North America. It is estimated that 25% of farmers are operating below the basic level of 4R BMPs, while three levels (3-tiers) of implemented 4R N management, to achieve improved crop recovery and increased crop yield potential, are used by other farmers:

- **Basic -** 50% of farmers
- **Intermediate -** 20% of farmers
- **Advanced** -5% of farmers

The seven regionally-sensitive "strawdog" 3-tiered 4R-N management frameworks provided to the March 2015 workshop participants were for:

- **Non-irrigated Corn-Soybean in the West**
- **Non-irrigated Corn-Soybean in the North Central Upper Mid-West**
- **Non-irrigated Corn-Soybean in the East Central**
- **Irrigated Corn-Soybean in the North**
- **Wheat in the Northern Great Plains**
- **Wheat in the Southern Great Plains**

Scientists at the workshop divided into regional cropping system breakouts and reviewed, discussed, and revised the "strawdog" frameworks. Each of the seven revised frameworks was presented to the entire body of participating scientists by volunteered, breakout session spokespersons. Each framework was then subjected to a "blind" but transparent voting process (*using clickers and real-time voting summary and display*), to "approve" or "not approve". IPNI,

TFI, and FC staff at the workshop served only as discussion facilitators, and were not involved in revising the "strawdog" frameworks, nor did they vote on the revised frameworks.

RESULTS AND DISCUSSION

Six of the seven revised 3-tiered 4R N management frameworks were unanimously approved by the N science workshop participants. An example of the unanimously approved 3-tered 4R-N-management corn system frameworks is shown in **Figure 3.** Because time ran short at the March workshop, final revisions to the N management framework for **Irrigated Corn-Soybean in the South** were deferred to IPNI's coordination. Those specific framework revisions were voluntarily led by University of Arkansas N scientist - *Dr. Trent Roberts,* who attended the workshop and subsequently enlisted the help of three other selected N management scientists in the southern U.S.: from Mississippi State University – *Dr. Wayne Ebelhar,* Louisiana State University – *Dr. H.J. "Rick" Mascagni,* and the University of Georgia – *Dr. Glen Harris.* That developed framework will be shared with the project SAG, and then be subjected to consensus approval of all scientists who attended the workshop in March.

Performance Level	Right Source	Right Rate	Right Time	Right Place	N_2O Reduction Modifier
Basic	• Guaranteed or known analysis for all fertilizer sources or book values for manure • For fall applications use ammoniacal or ammonium forms • No fall N on sandy soils • Any source for spring N	• In states with the MRTN approach, use realistic N and crop prices when using the N Rate Calculator • For recommendations using a yield goal approach, set realistic yield goals using average of last 5 years of production levels with an added small %'age increase. • Properly credit previous legume crops and account for all N sources, including N-containing phosphate fertilizers and manure applications.	• Pre-plant and side-dress applications are preferred over fall. • In fall, apply only when soil temperatures at 4-6 in. are sustained below 50F. • Do not fall-apply N on sandy soils, soils with high permeability, fine-textured poorly drained soils or soils overlaying fractured bedrock. • Do not apply urea on frozen or snow covered soils • Apply manure according to manure management plan	• Any placement	•
Intermediate	• For fall apps in higher rainfall areas, include NI • For pre-plant or side-dress applications on poorly drained soils subject to denitrification or medium textured soils where nitrate loss is likely, use a NI with ammonium sources. • Base manure applications on manure testing • Controlled release sources for pre-plant; • If Urea/UAN un-incorporated, use a UI	• Where appropriate and properly calibrated and supported by local research use PPNT or PSNT • Manure application rate should not exceed approved manure management plan	• No application of primary N source fertilizers in the fall (MAP/DAP allowed) • Fall applied Manure N is allowed with a NI • Apply a portion of N at pre-plant or seeding; apply remaining N at side-dress after an in-season assessment	• Under conservation tillage, apply urea or UAN at the surface with a UI • Apply some N at planting adjacent to the seed row.	•
Advanced	• Use the following when there are proven, acceptable probabilities of efficacy under local conditions: controlled-release N, sources with multiple inhibitors, or other technological advancements in fertilizer forms. • Use an adaptive management process based on on-farm, replicated studies to evaluate efficacy of new fertilizer technologies, using crop yield response, NUE and ROI	• Use an in-season, plant-based assessment of crop N status, such as a chlorophyll meter or other sensor, coupled with a split N application rate based on calibrated sensor readings; OR • Account for temporal variability in crop need with calibrated decision support systems; OR • Account for spatial variability in crop need using crop sensors, remote sensing, management zones, soil mapping units, or other data layers; OR • Use an adaptive management process based on on-farm, replicated studies for N rates.	• Use an adaptive management process based on on-farm • Use replicated studies to evaluate efficacy of new fertilizer technologies, using crop yield response, NUE and ROI	• Account for spatial variability in crop need using crop sensors, remote sensing, management zones, soil mapping units, or other data layers	•

Figure 3 – Example 3-tiered 4R-N-management framework representing N. Central Upper Midwest, non- irrigated corn (wetter and cooler than the west; WI, E. MN, IA, MO, IL – between East and West and northern part)

The March workshop was considered a great success in establishing the six approved 3-tiered 4R-N- management frameworks for improved N use efficiency (*apparent crop N recovery*) and crop productivity. Unfortunately, the workshop participants were not quite ready to assign N_2O emission reduction modifiers to each of the approved tiered-4R-N management frameworks. Yet, each participant did express interest in continued science coordination and follow-up efforts to arrive at the possible tiered N management, N_2O emission reduction modifiers to N-rate-based N_2O emissions estimates.

The SAG and workshop participants suggested that the USDA-supported agriculture N_2O emission modelers - Dr. Steve Del Grosso and Dr. Steve Ogle - *who help lead the U.S. annual agricultural GHG inventory reporting to the U.S. Environmental Protection Agency, as part of the U.S. total annual GHG inventory report* (http://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html) take one of the approved 3-tiered 4R-N management frameworks through some hybrid DNDC/DAYCENT N_2O emission modeling runs, to evaluate outcomes. However, subsequent discussions with those scientists and several SAG members indicated that additional work may first be needed, to be sure that improved N use efficiency (*based on actual field-measured crop N uptake*) in major corn production systems in the U.S. is indeed correlated with field-measured reduced N_2O emissions. Such a correlation has been shown by scientists in Europe between crop yield-scaled N_2O emissions and crop N uptake efficiency (based on above-ground crop N recovery) (van Groenigen et al., 2010).

To help address this particular science gap and need, an expansion of the existing 4R Research Fund-supported study by Dr. Tony Vyn (http://research.ipni.net/project/IPNI-2014-USA-4RN25) was suggested. A two-part proposal was developed by Dr. Vyn to:

- 1) gather existing field-measured corn N uptake and recovery data in 4R N management N_2O emission studies by Dr. Ardell Halvorson (*retired USDA ARS; irrigated semi-arid corn systems*) and Dr. Tony Vyn (*rainfed humid corn-soybean systems*); additionally, data will be gathered from other USDA ARS GRACEnet projects through cooperation by Dr. Rod Venterea (*USDA ARS*); and
- 2) measure N_2O emissions from additional field studies in Indiana to expand the data collected on 4R treatment contrasts.

The two-part proposal by Dr. Vyn was subjected to review, rating, and approval by the 4R Research Fund Technical Advisory Group (TAG), and then review by the 4R Fund Management Committee. Those two groups approved support of the expanded work to investigate the apparent N recovery and reduced N_2O emissions relationships. Pending the outcome of those research efforts, the next steps might be to use those data to populate the three tiers of each of the seven 4R-N-management frameworks for corn-soybean and wheat production systems, with N_2O emission reduction modifiers (*i.e. coefficients*) that correspond to anticipated improved crop productivity and crop N use efficiency (*i.e. apparent crop N recovery*); and then engage the IPNI and TFI-led project SAG and the March N workshop participants to receive their feedback and consensus approval. The data gathered might then also be used to more fully calibrate and parameterize the USDA and Colorado State University hybrid DNDC/DAYCENT prediction model mentioned above.

This project will also attempt to move the Field to Market FPC N2O emission estimator away from a "one-size-fits-all" approach to emissions estimates and to a regionally sensitive approach. The seven 3-tiered 4R-N-mangement frameworks will be aligned with specific Land Resource Regions (LRRs; 20 within conterminous U.S.) used by the USDA NRCS (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053624) and include estimated crop, soil texture, and N rate baseline conditions described by USDA in its entity-scale GHG quantification report (Eve et al, 2014).

In addition to the value of these respective N management frameworks in identifying opportunities for, and reductions in, N_2O emissions, it is believed that these frameworks have much relevance to the water quality metric in the Field to Market FPC. By using these frameworks in both the GHG and water quality metrics in the FPC, it seems possible to avoid the

potential for unintended "tradeoffs" in environmental N loss; for example, reducing N_2O emissions but increasing the risk for runoff or subsurface drainage losses of N.

SUMMARY

The IPNI-TFI-led N2O project described here, is helping move the Field to Market FPC to a more 4R sensitive status, and enable the FPC to become more Land Resource Region, crop, and soil sensitive. This effort is also bringing cropping system N management scientists and GHG N_2O emission scientists together in the U.S. and Canada, to broaden the science base and approaches used in developing and adapting sustainability metrics within the Field to Market FPC.

ACKNOWLEDGEMENT

Grateful appreciation is expressed to each scientist who has and continues to cooperate with IPNI in this science endeavor. We also thank members of the industry who have contributed to the 4R Research Fund which is helping support the field research and science synthesis that will advance more sustainable cropland N management practice implementation.

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