SUSTAINABLE AGRICULTURE RESEARCH GAPS PROJECT: N CYCLE

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1.0 OBJECTIVES

- Collect and analyze fertility recommendations for nitrogen management from land-grant universities across the Unites States,
- Describe what information is embedded in recommendation models,
- Learn how recommendations are updated,
- Identify which are the main research and extension gaps associated with N management,
- Identify which are the main sources of information farmers and their advisors trust/consult the most when it comes to implementing best management practices related to nitrogen management,
- Understand how much importance farmers place in those sources of information and how likely is that each of them will influence their actual N management strategies, and the adoption of best management practices.

2.0 MAIN TAKEWAYS

- **Recommendation models** for nitrogen management from land-grant universities in the United States are moderately variable in terms of factors they consider, with high influence of crop type, management strategies, the region of the country they are created for, and the university they come from.
- Considering this variability, advancement of recommendation models would highly benefit from **cross-collaboration** activities among universities and other agencies. This is especially important to develop and refine existent models beyond states' borders, considering variations in environmental conditions as primary factors. Furthermore, this should also contribute to a more efficient use of those resources allocated to improvement of recommendation models.
- In general, extension publications and N recommendations need to address more in depth all aspects of **4Rs strategies** (right source, right time, right rate, and right place) for N fertilizer application.
- Moreover, recommendations should promote adoption of **adaptive management strategies** integrating multiple tools available for field and sub-field adjustments of baseline scenarios obtained through regular N rate calculation tools (MRTN or yield-goal based approaches), according to local conditions. Better integration of

precision agriculture technology into the recommendations as one of the strategies for adaptive management is also needed. Moreover, development of real time sensors and tools that generate accurate local data, along with integrated data management software and precise models for definition of N needs may play a key role on adaptive management.

- In the extension publications reviewed there was a relatively small consideration for **precision agriculture technologies** for N management (i.e. canopy sensing, plant sampling, variable rate application, use of inhibitors, etc.). More content around these topics should be incorporated in extension publications for farmers and their advisors to use as a guide for effective implementation at the field level.
- The Maximum Return to Nitrogen (MRTN), and other yield-goal based approaches are the main baseline strategies used in the United States for formulation of recommendations, with different levels of complexity. Both have advantages and disadvantages and are better suited for different soil and climate conditions. The potential for using a mass balance approach to fertilizer N management (characteristic of yield-goal based strategies) is greater in places with lower annual rainfall. However, use of such approaches may be less successful in higher annual rainfall regions.
- The **MRTN** approach requires frequent updates on results from N response trials to provide accurate estimates. Consequently, resources need to be allocated in on-farm research programs intended to develop and/or update these databases. Also, this method would benefit from additional research that determines optimal number of response trials.
- **Yield-goal** based approaches would benefit with research that better explains the nutrient use efficiency factors associated with different sources of N for crop growth, since an important component of this method includes accounting for several “N credits”. Also, with the creation of refined, user-friendly, dynamic soil, crop and environmental models that better predict crop nutrient needs at the field and sub-field level, both before and during the crop season, using readily-available and localized data (both empirical and real time data).
- Other **research gaps** detected were to identify new strategies to minimize N losses, as well as to validate new retail products that typically claim a yield increase or other agronomic benefits if applied, for which producers look to University Extension for answers regarding their efficacy (i.e. inhibitors). Similar research gaps along these lines

include to study the impact of conservation practices on N recommendations, and to improve the overall strategy for more efficient in-season N application (integration of available tools for better adaptive and reactive management according to weather and crop status).

- Regardless of the direct source of information farmers consult the most when it comes to N management, results from **research conducted in land-grant universities** is the base that most recommendations from the public and private sector build on. Therefore, funding directed to research related to nutrient management at the university level would likely benefit the advancement of recommendations models at multiple levels, even when producers do not consult University Extension resources directly.
- There is a strong need to allocate more funding for **extension programming** at land-grant universities to improve communication about N management strategies, and especially to those projects that promote innovative ways to reach multiple audiences through various digital mediums.
- The response data from the Trust in Food survey indicated from which sources producers have received nitrogen management information in the last year, and which sources are the most trusted. Among other insights, it is crucial to understand why producers do not place more trust in unbiased sources such as University Extension and government agencies. Efforts should be made to understand the lack of trust and find strategies to be recognized as more trusted sources of information regarding nutrient stewardship.

3.0 METHODS

To accomplish the objectives listed, four main activities were carried out:

3.1 Internet Search for Extension Publications

To accomplish the objectives listed, four main activities were carried out: An internet search was conducted to collect fertility recommendations for nitrogen management from land-grant universities across the United States. For the documents and tools found in each of the land-grant universities' websites, an assessment was conducted to identify which

were the most important factors embedded in each of the recommendations.

- Search engine: Google (web explorer was Google Chrome).
- Example of key words utilized:
    - *"University of Georgia + Nitrogen recommendations for cotton"*
    - *"University of Georgia + Fertilizer recommendation for cotton"*
    - *"University of Georgia + Fertility recommendations for cotton"*
    - *"University of Georgia + Nutrient management for cotton"*
- Crops and Universities: three main crops were considered, to narrow down the scope of the review.
    - Corn: University of Nebraska-Lincoln, Iowa State University, University of Minnesota, University of Wisconsin, Michigan State University, University of Illinois, Purdue University, Kansas State University, and University of Missouri.
    - Cotton: University of Georgia, Auburn University, Mississippi State University, University of Arkansas, Oklahoma State University, and Texas A&M.
    - Wheat: Kansas State University, North Dakota State University, Montana State University, Washington State University, Oklahoma State University, and University of Idaho.
- Inclusion criteria for the documents:
    - Extension publications (no peer-reviewed journal publications),
    - Documents published after the year 2000,
    - Documents summarizing overall concepts around N fertility management ("comprehensive documents").
    - Only results in the first page of the search engine were considered, plus other documents found while exploring the opened web pages.
- Analysis of the documents and tools: for each of the documents and tools found in the universities' websites, the following properties were extracted:
    - Year of publication/update,
    - Main principles for the overall recommendation,

Specific factors mentioned in the document as the most important considerations to take into account when defining a nitrogen application were compiled and coded according to similarities.

3.2 Interview with Fertility Specialists

Thirty-minute interviews were conducted with fertility specialists from multiple land-grant universities and other organizations across the US, to assess their perceptions about N management recommendations.

- Interviews were carried out with fertility specialists from:
    - University of Georgia,
    - University of Arkansas,
    - Iowa State University,
    - University of Minnesota,
    - University of Illinois,
    - Purdue University,
    - Texas A&M
    - The Fertilizer Institute.
- The structure of the interview was based on 5 main questions:
    - *From your perspective, which are the main sources of information farmers and their advisors in your state/region trust/consult the most when it comes to implementing BMPs related to nitrogen management?*
    - *What is/are the main principle/s behind the recommendation/s university gives farmers when it comes to N management for corn/wheat/cotton/peanuts?*
    - *What is the frequency these guidelines are updated?*
    - *Nowadays, which are the main gaps/needs in terms of research related to nitrogen management in your state/region?*
    - *Nowadays, which are the main gaps/needs in terms of extension related to nitrogen management in your state/region?*

After the interviews were completed, annotations from all the conversations were analyzed to identify common themes for each of the questions. Conclusions were made according to the results of this analysis, as well as from special notes made by the interviewers and specific comments from the specialists.

3.3 Farmers' Survey Methodology

Two questions were integrated into a larger survey administered to farmers in the summer of 2020 by Trust in Food in partnership with Field to Market.

- Questions
    - *Q1: In the past year, have you received information about nitrogen management strategies from any of the following?*
    - Options were:

- ☐ Fertilizer supplier / Seed supplier / Contract applicators / Farm cooperatives,
- ☐ University Extension,
- ☐ Crop and fertilizer consultants (independent or corporate),
- ☐ Relatives / Friends / Neighboring farmers / Other farmers,
- ☐ Farm magazines / publications in television or social media,
- ☐ Farm events or demonstrations,
- ☐ Commodity groups / Farm Bureau,
- ☐ Natural Resources Conservation Service / Farm Service Agency,
- ☐ Landlords,
- ☐ Online calculators / Internet searches / Internet forums or chats.
- ☐ A nonprofit conservation or environmental group
- ☐ Other

- *Q2: How much do you trust the views or information about nitrogen management provided by each of the following sources as it applies to your farming operations? (same response options as above)*
- Scale was “Don’t know”, “Not at all”, “Some”, “A lot”

3.4 Review of Research Publications

Research publications relevant for the project were reviewed and summarized.

4.0 RESULTS AND CONCLUSIONS

4.1 Internet Search for Extension Publications

The main findings from extension publications for corn, cotton, and wheat are shown in Tables 5.1 to 5.13 (Appendix). A summary of the results is presented here.

- Recommendation Principles
  - The Maximum Return to Nitrogen (MRTN) is recommended by some universities as the main approach for N rate calculation, especially for corn in the Midwest in states with greater amounts of annual rainfall.

- A yield-goal based approach is widely recommended by multiple universities as the main method to define N application rates for multiple crops, although some universities no longer support this approach. Yield-goal strategies appear to be more common in states with lower amounts of annual rainfall. Some recommendations include an economic component (embedded into the N rate calculation models, for example), and others do not (N rates are calculated only based on plant N requirements and N credits from different sources).

- <u>Most Relevant Factors Embedded in Recommendations for N management</u>
  - For corn, the most important factors embedded in recommendations from the extension publications reviewed include crop rotation, timing of the application, prices of fertilizer and grain, soil nitrate levels and manure applications.
  - For cotton, the most important factors embedded in recommendations from extension publications include timing of N application, yield goal and history, and crop rotation.
  - For wheat, the most important factors embedded in recommendations from extension publications include soil nitrate levels, yield goal, crop rotation, timing of the application, and soil organic matter.
  - For the crops considered in this review, factors associated with 4Rs strategies seem to be mentioned to certain extent in most of the extension publications (timing, fertilizer type, application method, and application rate). However, not all universities seem to be covering all these aspects to the same extent.

- <u>Tools for N Rate Calculations</u>
  - Depending on the crop type, tools for calculation of N rate may or may not be publicly available (tools were found for corn and wheat, but not for cotton).
  - When several tools were found for a specific crop from different universities, there is a lack of uniformity in the principles behind them, as well as in the factors they take into consideration to formulate the recommendation. Most of the tools use the yield-goal based approach (with or without an economic component embedded), and some of them utilize the MRTN approach.

    - For corn, the most important factors embedded in the tools for N rate calculation are crop rotation, soil characteristics, corn and fertilizer price, timing of the application and fertilizer type.
    - For wheat, the most important factors embedded in the tools for N rate calculation are soil characteristics, yield goal, crop rotation, tillage type, and wheat price.

- Others
    - There is variability on how frequently new nitrogen recommendations guidelines are published/updated among different universities. However, means and medians for year of publication/update indicate that most of the publications reviewed were released at least 4 or 5 years ago.

4.2 Interview with Fertility Specialists – Summary of Responses

Question 1: *From your perspective, which are the main sources of information farmers and their advisors across the US trust/consult the most when it comes to implementing BMPs related to nitrogen management?*

- There is variability in different states for the primary source of information farmers use when it comes to N management recommendations. In general, the main sources mentioned by specialists were extension, private crop consultants, fertilizer suppliers/dealers, private labs/companies.
- However, since recommendations from the private sector rely to some extent on University research and advice, these guidelines eventually reach farmers indirectly. Also due to this factor, universities play an important role in applied research around N management strategies.
- Extension programming in some universities is strategically directed to certain audiences (private agronomists, for example), targeting those who are the sources of information farmers tend to consult/trust the most in those states.
- In general, specialists from southern states highlighted extension as the source of information farmers consult the most. Specialists from the Midwest tended to indicate the private sector is the main source of information for farmers.

Question 2: *What is/are the main principle/s behind the recommendation/s university gives farmers when it comes to N management for corn/wheat/cotton/peanuts?*

- As identified when reviewing the extension publications, the main principles behind the recommendations for N applications varied for different states, crops and management strategies.
- Most specialists from universities that do not use the MRTN approach indicated that their states use a yield-goal/yield-potential based strategy.

Question 3: *What is the frequency these guidelines are updated?*

- Update frequency varied among different universities, and for different crops within each state (mostly related to how important each crop is).
- For those states using the Corn Nitrogen Rate Calculator (CNRC) (several midwestern states, applying the MRTN approach), research results from N rate trials are used for an annual update to the database of the calculator.
- Specialists from universities not using the MRTN approach also indicated performing N fertility trials to update the guidelines, although with lower frequency.

Question 4: *Nowadays, which are the main gaps/needs in terms of research related to nitrogen management in your state/region?*

- In states where universities recommend using the MRTN approach, there is a strong need for expanding the number of N rate trials to cover a more diverse array of soil, climate, and management conditions. This information is a vital component of the database behind the Corn Nitrogen Rate Calculator.
- To identify innovative ways to reduce N losses through different pathways (including in-field and out out-of-field practices), as well as to consider more environmental variables in N-related fertility trials.
- To test new products available in the market for N management (i.e. inhibitors), to provide accurate and reliable information to raising demands from multiple audiences of the agricultural sector.
- To improve recommendations according to “reactive management” (adjustment of in-season applications, according to environmental conditions, weather). Also, defining the linkage between timing of

appearance and severity of N deficiency symptoms in corn in order to make sense of canopy-sensing and how N should be managed.
- To measure the overall potential of applying multiple BMPs related to 4R strategies simultaneously (rate, sources, inhibitors, timing, etc.) on N-use efficiency and N-loss reduction.
- To develop strategies to improve N management in cotton, like variable rate application.
- To study the impact of cover crops and other conservation practices on nitrogen and carbon cycling, and how that affects the N recommendations and the economics around N applications.
- In manure applications, there is a need to study the nitrogen dynamics for different application dates, rates, manure types, etc.
- To investigate how soil organic matter dynamics affect nitrogen management at the field level.
- Developing the resources needed to have precise micro-weather predictions for localized conditions to improve N use efficiency.
- Data manipulation of precision agriculture is lacking to be streamlined to combine weather, sensors, machine data to get better efficiency. We don't make good use of satellite data for example, other data, to be cost effective and useful for recommendations.

Question 5: *Nowadays, which are the main gaps/needs in terms of extension related to nitrogen management in your state/region?*

- Funding for cooperative extension in land-grant universities for multiple purposes: increase number of extension educators, number of extension appointments in faculty members, resources invested in applied research, etc.
- Methods and resources to better identify and characterize those audiences the universities work with, and audiences they are not reaching with their extension programming, to better target extension activities.
- To develop new extension programming strategies to better connect with a wide range of audiences, including the oldest and youngest generations of farmers.
- To develop multiple strategies to overcome the cultural and social barriers that interfere in the adoption of conservation practices related to N management.

- To improve the cost-effectiveness of precision agriculture and N recommendations. More case studies needed so farmers can adopt more practices without fear.
- To promote better partnerships among universities, NGOs, private companies, to address these challenges more collaboratively.

4.3 Farmers' Survey Analysis

The survey responses were received on September 21st, 2020. The responses analyzed were from the subset of producers that indicated they grow 50+ acres of either corn or soybeans, as recommended by Trust in Food staff; 448 producers responded to at least one portion of each question.

For the question "*In the past year, have you received information about nitrogen management strategies from any of the following?"*, the response data is shown in Figure 4.3.1.

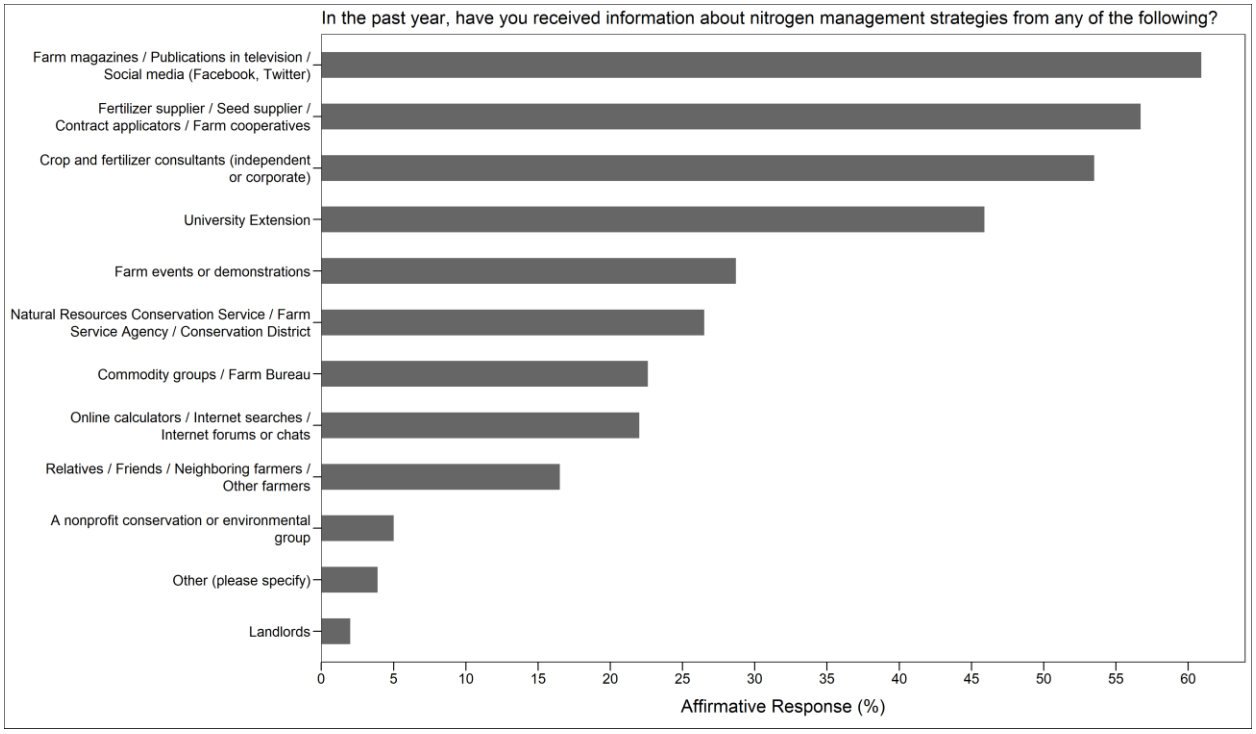

Figure 4.3.1. Affirmative responses to the first Trust in Food survey question. Sources are sorted from high to low affirmative response.

The top four sources of nitrogen management strategies were Farm Magazines/TV/Social Media, Fertilizer and Seed Suppliers/Applicators/Coops, Crop Consultants, and University Extension; producers indicated that at least 45-60% of them had received information

from those sources in the past year. The bottom four sources included Online Calculators/Internet Forums, Relatives/Neighbors, Conservation or Environmental Groups, and Landlords, with affirmative responses ranging 2-22%.

The response data for the second question, "*How much do you trust the views or information about nitrogen management provided by each of the following sources as it applies to your farming operations?"*, is shown in Figure 4.3.2.

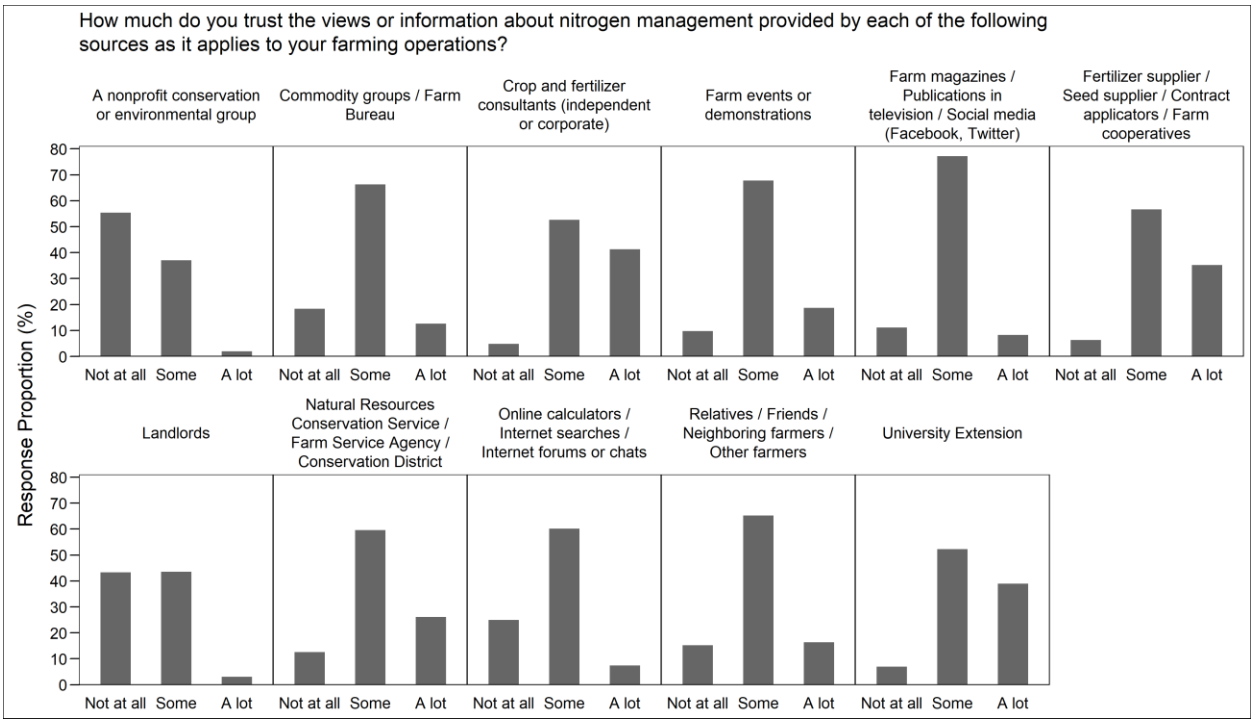

Figure 4.3.2. Response proportion according to how much trust producers assign to each of the sources. Sources are sorted alphabetically.

For the second question, there was also the option to respond "Don't know"; those responses were excluded from Figure 4.3.2 since the proportion of "Don't know" responses was very low and changed minimally across the various sources.

The most trusted sources for nitrogen information, indicated by the producers who responded they trust those sources "A lot", included Crop and Fertilizer Consultants (41%), University Extension (39%), Fertilizer and Seed Suppliers/Applicators/Coops (35%), and government agencies such as NRCS (26%). Least trusted sources for which producers responded with "Not at all" included Conservation or Environmental groups, Landlords, Online Calculators, and Commodity Groups. Producers responded that 18-55% do not trust at all the nitrogen information coming from those sources.

Many of the least trusted sources indicated by the second question (Figure 2) are also listed in Figure 4.3.1 as the sources from which producers have not received nitrogen management information. This poses the question if producers do not trust the nitrogen information from such sources because those organizations are not reaching to producers in the first place, or if other variables are at play.
Nitrogen management sources that could be considered unbiased and free of commercial interests, such as University Extension or government agencies like NRCS, seem to be relatively trusted compared to other sources; 39 and 26% of producers indicated they trust those sources a lot, respectively. However, efforts should be made to understand why farmers do not place more trust in University Extension and government agencies regarding nitrogen management and establish long-term goals to be perceived as more trusted sources of nutrient stewardship.

4.4 Review of Research Publications

Morris, T. F., Murrell, T. S., Beegle, D. B., Camberato, J. J., Ferguson, R. B., Grove, J., … Yang, H. (2018). Strengths and limitations of Nitrogen rate recommendations for corn and opportunities for improvement. *Agronomy Journal*, *110*(1), 1–37. https://doi.org/10.2134/agronj2017.02.0112

Summary and Discussion:
This journal paper describes multiple strategies and tools utilize nowadays across the United States for nitrogen management in Corn. Although focused on this crop, the publication highlights the importance of improving recommendation models for nitrogen management nationwide in multiple crops, for agronomic, economic, and environmental reasons.
As found in the review of extension publications, the article confirms the need of strengthening the message about the “4R” approach in N recommendations, and with that, the implementation of management practices to address all aspects of this strategy. Likewise, the paper validates that all models currently in place for recommendations have advantages and disadvantages, that make them a better fit for certain regions of the country compared to others (specific soil and climate conditions). In that regard, the article indicates that the potential for using a mass balance approach to fertilizer N management (characteristic of yield-goal based strategies) is greater in places with lower annual rainfall. This confirms the findings of the extension publications’ review.

The article also expands on current needs for different models. Yield-goal based approaches would benefit with research that better explains the nutrient use efficiency factors associated with different sources of N for crop growth, since an important component of this method includes accounting for several “N credits”. Also, with the creation of refined, user-friendly, dynamic soil, crop and environmental models that better predict crop nutrient needs at the field and sub-field level, both before and during the crop season, using readily-available and localized data. The MRTN approach requires frequent updates on results from N response trials to provide accurate estimates. Consequently, and like the interviews with Faculty members also revealed, resources need to be allocated in on-farm research programs intended to develop and/or update these databases. Also, this method would benefit from additional research that determines optimal number of response trials.

Finally, the paper highlights the importance of advancing towards an “adaptive management” of nitrogen, which implies adjusting the general recommendations generated by models used nowadays, according to local conditions. Development of real time sensors and tools that generate accurate local data, along with precise models may play a key role on adaptive management. The review conducted through this project showed a lack of information about precision agriculture technologies like these ones, being incorporated in regular extension publications producers may finds searching through internet browsers. On the same line, the journal article indicates the existence of limitations on the development of these technologies, and the adoption by farmers. Researchers interviewed also pointed the necessity of developing more accurate tools for adaptive and reactive management of N.

5.0 APPENDIX

Table 5.1. Extension publications reviewed for N fertility management in Corn.

University	Resource	Year of Publication / Update
University of Nebraska-Lincoln	Nutrient management suggestions for corn	2019
Iowa State University	Extension publications / Nitrogen use in Iowa Corn Production	2018
	Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn	2015
	Site specific 4R nutrient management planning / Nitrogen Management	N/A
University of Minnesota	Fertilizing corn in Minnesota / Nitrogen Guidelines	2018
University of Wisconsin	Nutrient application guidelines for field, vegetable, and fruit in crops in Wisconsin / Nitrogen	2012
	University of Wisconsin Nitrogen Guidelines for Corn	N/A
University of Illinois	Managing Nitrogen for Corn in 2020 / Farmdoc daily article	2020
	Managing Nitrogen / Illinois Agronomy Handbook	N/A

Purdue University	Nitrogen Management Guidelines for Corn in Indiana	2019
	Soil Sampling to Assess Current Soil N Availability	2017
	Late-Season Nitrogen Application for Corn	2018
Kansas State University	Soil Test Interpretations and Fertilizer Recommendations	2003
	Nutrient management / Nitrogen	N/A
University of Missouri	Fertilizer Management for No-Till Corn and Grain Sorghum in Missouri	1994
	Nitrogen Management for No-Tillage Systems in Missouri	1993
	https://extensiondata.missouri.edu/pub/pdf/agguides/pests/ipm1027.pdf	2006
	Preplant Nitrogen Test for Adjusting Corn Nitrogen Recommendations	2000

Table 5.2. Summary of extension publications reviewed for N fertility management in corn.

University	Documents Reviewed	Main Principle for N Rate Recommendation	Year of Publication/Update
University of Nebraska-Lincoln	1	**Yield goal[1] + Adjusted yield goal[2]**	**Mean:** 2011 **Median:** 2016 **Mode:** 2018
Iowa State University	3	**MRTN[3]**	
University of Minnesota	1	**MRTN**	

[1] Yield-Based N Recommendations are those where the total N application rate is defined according to predicted yield for the field (which defines the quantity of N needed by the plant), and what is provided by the soil (other N credits different from fertilizer).
[2] Adjusted by corn and fertilizer price.
[3] Maximum Return to Nitrogen: recommendation system based on information from N response trials, where N application rates are defined according to the maximum economic return to fertilizer, and main adjustments are made according to N and corn prices.

	University of Wisconsin	2	**MRTN**	
	University of Illinois	2	**MRTN**	
	Purdue University	3	**MRTN**	
	Kansas State University	2	**Yield Goal**	
	University of Missouri	4	-----	
Total	**8**	**18**		

Table 5.3. Summary of the most relevant factors mentioned in extension publications as important considerations to take into account when defining a N application in corn.

Factor	%[4]	Factor	%[5]
Soil nitrate levels	**88**	Last crop: type (rotation)	**72**
Corn price	**88**	Timing of N fertilizer application	**67**
Last crop: type (rotation)	**88**	Fertilizer Price	**61**
Manuring: type of manure	**88**	Corn Price	**56**
Manuring: amount applied	**88**	Soil nitrate levels	**50**
Fertilizer Price	**88**	Manuring: type	**50**
Timing of N fertilizer application	**75**	Manuring: amount	**50**
Region of the state	**63**		
Yield goal	**63**		
Manuring: N concentration of manure	**63**		
Fertilizer application method	**63**		
SOM content	**50**		
Last crop: residues management	**50**		

[4] Percentage of Universities that mention in at least one of their extension publications that this is an important factor to take into account when defining a nitrogen application.
[5] Percentage of the total publications that mention this is an important factor to take into account when defining a nitrogen application.

Fertilizer type	**50**		
Irrigation: Yes/No/Amount	**50**		

Table 5.4. Publicly available tools for N rate calculation in corn found in the universities' websites.

	University	Tools	Principles / Use
	University of Nebraska-Lincoln	*Maize-N Model*	**Evaluate attainable yield, N uptake, and fertilizer N required.**
		UNL Corn N Calculator	**Yield Goal + Adjusted Yield Goal[6]**
	University of Minnesota	*University of Minnesota Supplemental N Calculator*	**Calculate in-season N needs**
	Iowa State University	*Corn Nitrogen Rate Calculator*	**MRTN[7]**
	University of Wisconsin		**MRTN[8]**
	University of Illinois		**MRTN[9]**
	Purdue University		**MRTN[10]**
	Kansas State University	*KSU Fertilizer Recommendations*	**Yield Goal**
	University of Missouri	No Tools.	
Total	**8**	**5**	

[6] Adjusted based on corn and N price.
[7] Extra adjustment by state region is available.
[8] Extra adjustment by soil type is available.
[9] Extra adjustment by state region is available.
[10] Extra adjustment by state region is available.

Table 5.5. Most relevant input needed to run the tools identified for calculation of N rates in corn.

Factor	%[11]
Last crop: type (rotation)	80
SOM content	60
Soil nitrate levels	60
Corn Price	60
Fertilizer type	60
Timing of N fertilizer application	60
Fertilizer Price	60

[11] Percentage of tools where this specific input is needed to calculate the N application rate.

Table 5.6. Extension publications reviewed for N fertility management in cotton.

University	Resource	Year of Publication / Update
University of Georgia	Cotton Fertilization	2018
	2019 Georgia Cotton Production Guide	2019
Auburn University	Nutrient Recommendation Tables for Alabama Crops	2012
	Research-based Soil Testing and Recommendations for Cotton on Coastal Plain Soils	2010
Mississippi State University	Cotton - Nitrogen	
	Inorganic Nutrient Management for Cotton Production In Mississippi	2017
University of Arkansas	2020 Arkansas Cotton Quick Facts	2020
Oklahoma State University	Cotton Yield Goal – Nitrogen Rate Recommendation	2017
	Nitrogen Requirements of Contemporary Cotton Cultivars	2014
Texas A&M	Managing Nitrogen Fertilizer in Cotton	2011
	Nitrogen Management in Cotton	2009
	Nutrient Management for Texas High Plains Cotton Production	2009

Table 5.7. Summary of extension publications reviewed for N fertility management in cotton.

	University	Documents Reviewed	Main Principle for N Rate	Year of Publication/Update
	University of Georgia	2	**Yield Goal**	**Mean:** 2014 **Median:** 2014 **Mode:** 2017
	Auburn University	2	**MRTN**	
	Mississippi State University	2	**Yield Goal**	
	University of Arkansas	1	**Yield Goal**	
	Oklahoma State University	2	**Yield Goal**	
	Texas A&M	3	**Yield Goal**	
Total	**6**	**12**		

Table 5.8. Summary of the most relevant factors mentioned in extension publications as important considerations to take into account when defining a N application in cotton.

Factor	%[12]	Factor	%[13]
Timing of N fertilizer application	**100**	Timing of N fertilizer application	**92**
Yield goal	**67**	Yield goal	**75**

[12] Percentage of Universities that mention in at least one of their extension publications that this is an important factor to take into account when defining a nitrogen application.
[13] Percentage of the total publications that mention this is an important factor to take into account when defining a nitrogen application.

Yield History	**67**	Yield History	**75**
Soil texture	**50**	Last crop: type (rotation)	**50**
Last crop: type (rotation)	**50**		
Irrigation: Yes/No/Amount	**50**		

Table 5.9. Extension publications reviewed for N fertility management in wheat.

University	Resource	Year of Publication/update
Kansas State University	Soil Test Interpretations and Fertilizer Recommendations	N/A
	Nutrient management / Nitrogen	N/A
	Topdressing wheat with nitrogen: Timing, application methods, sources, and rates	2019
North Dakota State University	Fertilizing Hard Red Spring Wheat and Durum	2018
	North Dakota Fertilizer Recommendation Tables and Equations	2018
	Fertilizing Winter Wheat	2018
Montana State University	Developing Fertilizer Recommendations for Agriculture	2019
	Fertilizer Guidelines for Montana Crops	2005
	Nitrogen Management for Grain Yield	2016
	Practices to Increase Wheat Grain Protein	2012
Washington State University	Dryland winter wheat: eastern Washington nutrient management guide	2013
Oklahoma State University	OSU Soil Test Interpretations	2017
	Article	N/A

University of Idaho	Northern Idaho Fertilizer Guide - Soft White Spring Wheat	2007
	Northern Idaho Fertilizer Guide - Winter Wheat	2015
	Southern Idaho Fertilizer Guide - Irrigated Winter Wheat	2001
	Southern Idaho Dryland Winter Wheat Production Guide	N/A

Table 5.10. Summary of extension publications reviewed for N fertility management in wheat.

	University	Documents Reviewed	Main Principle for N rate	Year of Publication/Update
	Kansas State University	3	**Yield Goal**	**Mean:** 2014 **Median:** 2016 **Mode:** 2018
	North Dakota State University	3	**MRTN**	
	Montana State University	4	**Yield Goal**	
	Washington State University	1	**Yield Goal**	
	Oklahoma State University	2	**Yield Goal**	
	University of Idaho	4	**Yield Goal**	
Total	**6**	**17**		

Table 5.11. Summary of the most relevant factors mentioned in extension publications as important considerations to take into account when defining a N application in wheat.

Factor	%[14]	Factor	%[15]
Soil N levels	**100**	Soil N levels	**82**
Last crop: type (rotation)	**100**	Yield goal	**65**
Tillage type and operation	**100**	Last crop: type (rotation)	**65**
SOM content	**83**	Timing of N fertilizer application	**65**
Yield goal	**83**	SOM content	**53**
Last crop: residues management	**83**		
Timing of N fertilizer application	**83**		
Application Method	**67**		
Crop Variety	**50**		
Manuring: amount	**50**		
Manuring: N concentration	**50**		
Fertilizer type	**50**		
Fertilizer price	**50**		

[14] Percentage of Universities that mention in at least one of their extension publications that this is an important factor to take into account when defining a nitrogen application.
[15] Percentage of the total publications that mention this is an important factor to take into account when defining a nitrogen application.

Table 5.12. Publicly available tools for N rate calculation in wheat found in the universities' websites.

	University	Tools	Principles / Use
	North Dakota State University	*North Dakota Wheat Nitrogen Calculator*	**MRTN + Other N credits**[16]
	Montana State University	*Southern Agricultural Research Center – Fertilizer Recommendation*	**Yield Goal**
		Economics of Fertilizer Application	**Maximum Net Revenue**[17]
	Washington State University	*WSU Dryland Wheat Nitrogen Fertilizer Calculator*	**Yield Goal**
	Kansas State University	*KSU Fertilizer Recommendations*	**Yield Goal**
Total	**4**	**5**	

Table 5.13. Most relevant input needed to run the tools identified for calculation of N rates in wheat.

Factor	%[18]
SOM content	**100**

[16] This calculator uses the MRTN as the baseline approach, but also incorporates other factors into the calculation, such as historical productivity of the field, soil nitrates, region of the state, previous crop, tillage method, soil organic matter.
[17] Tool that calculates pounds of N at max. net revenue, taking into account soil nitrate, soil organic matter, yield goal, wheat price, N price, premium and discounts for protein content.
[18] Percentage of tools where this specific input is needed to calculate the N application rate.

Soil nitrate levels	**100**
Yield goal	**80**
Last crop: type (rotation)	**80**
Tillage type and operation	**60**
Wheat Price	**40**