Imagery-based crop nutrient management

Challenges, opportunities, and the role of AI

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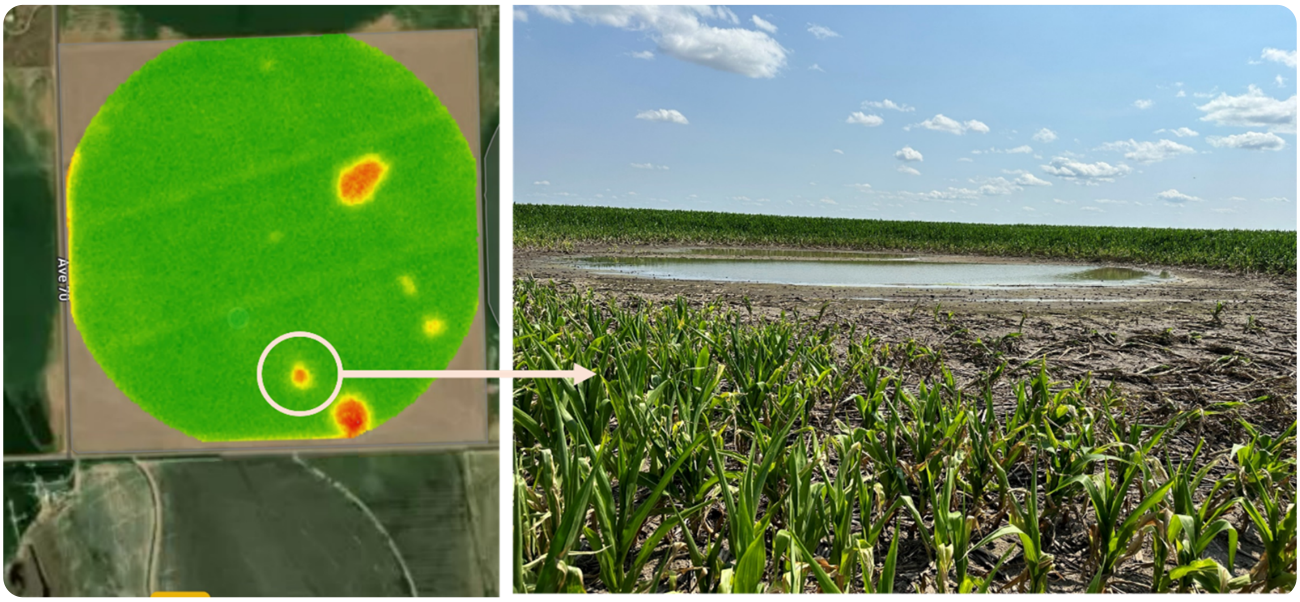

Figure 1. Left: Satellite imagery with a normalized difference red edge (NDRE) layer of a corn field in west-central Nebraska. Right: Photo taken of the actual site during field scouting.

Imagery-based nitrogen management systems offer tremendous potential for improving the efficiency of nitrogen use in agriculture. However, challenges such as cloud cover, image quality, and nitrogen leaching must be addressed for these systems to reach their full potential. Solutions driven by AI, combined with better agronomic practices, can help mitigate these challenges and reduce the environmental impact of nitrogen leaching, particularly in nitrogen-intensive regions. Earn 0.5 CEUs in Nutrient Management by taking the quiz for the article.

In recent years, imagery-based crop nitrogen management has emerged as a powerful tool for optimizing nutrient use, particularly nitrogen (N), in a variety of cropping systems. Technologies utilizing spectral indices like normalized difference red edge (NDRE) have enabled precise nitrogen monitoring, reduced nutrient losses, and enhanced yields. Having worked in a company dedicated to image-based agronomic intelligence for nutrient management, I have witnessed the potential this technology holds for transforming agriculture. However, significant challenges remain, including the impact of nitrogen leaching, especially in row crops, and the difficulties of acquiring high quality imagery in certain environmental conditions. This article will address these challenges, explore how artificial intelligence (AI) and machine learning (ML) can potentially mitigate them, and discuss the broader implications for nitrogen management.

The importance of spectral indices in nutrient management

Here I would like to start with an interesting story from my time scouting corn fields in west-central Nebraska. After scouting all the sectors that I was supposed to for nitrogen stress, I saw that the imagery showed a red blotch. Initially, I assumed it was either a diseased area or a low-lying section of the field. My curiosity made me go to that part of the field to witness what was going on. To my surprise, I found a ponded area, and it made me realize the importance of this technology as well as the associated risks (see Figure 1). Without addressing these types of anomalies and proper treatment of data, a red spot like this could be misinterpreted as nitrogen deficiency and actually receive higher fertilizer rate recommendations.

Normalized difference red edge is one of the most critical indices used to monitor nitrogen status in crops. Unlike other indices such as **NDVI** (normalized difference vegetation index), NDRE operates in the red-edge region of the light spectrum, allowing for a more sensitive detection of nitrogen stress in plants. The NDRE index helps identify early-stage nitrogen deficiencies, even when they are not visually apparent, enabling timely and precise nutrient interventions. I was able to experience this firsthand when I was scouting fields in eastern Nebraska (Figure 2). The imagery showed early signs of nitrogen deficiency in some parts of the field, which was hard to observe with my eyes.

However, nitrogen is not the only nutrient that crops require in balanced amounts. Other indices can target different nutrients, each critical for plant health. For instance, the **chlorophyll index** (CI) is used to estimate chlorophyll content and can be useful for both nitrogen and phosphorus monitoring while the **soil-plant analysis development (SPAD) index** is often used to evaluate chlorophyll levels and general plant health. Together, these indices offer a more comprehensive understanding of nutrient status and can inform more nuanced nutrient management strategies.

Figure 2. Scouting a corn field in eastern Nebraska.

Nitrogen leaching

While nitrogen management tools like NDRE are valuable for optimizing nutrient application, nitrogen leaching remains a significant issue. Nitrogen leaching occurs when nitrate (NO_3^-) moves beyond the root zone due to excessive rainfall or irrigation, eventually contaminating groundwater and nearby water bodies. This is especially problematic in regions like the Corn Belt where intensive corn production relies heavily on nitrogen fertilizers to sustain high yields. There are environmental, public health, and economic effects:

1. **Environmental impact**: Nitrogen leaching contributes to water contamination, which leads to the eutrophication of freshwater ecosystems, harming aquatic life and creating hypoxic zones like the infamous "dead zone" in the Gulf of Mexico.

2. **Public health risks**: Nitrate contamination in drinking water supplies poses serious health risks, particularly for infants, where it can cause conditions such as methemoglobinemia or "blue baby syndrome."

3. **Economic consequences**: From an agronomic perspective, nitrogen that leaches from the soil is nitrogen wasted, reducing nitrogen use efficiency (NUE) and leading to increased input costs without corresponding yield gains.

Challenges in imagery-based systems

One of the primary challenges of imagery-based nitrogen management is the difficulty in acquiring high quality images due to cloud cover, haze, and other atmospheric conditions. Cloud cover during the growing season can obstruct satellite or airborne sensors, limiting the availability of reliable imagery. This results in incomplete or delayed data, which hinders timely decision-making in nitrogen management.

Despite these challenges, advancements in artificial intelligence (AI) and machine learning offer potential solutions. Artificial intelligence can play a critical role in improving the quality of imagery-based nitrogen management systems and addressing issues like nitrogen leaching:

1. **Data imputation and cloud removal**: Machine-learning models can be trained to predict the state of the crops beneath cloud cover, using historical data and weather patterns to fill in gaps. Synthetic images that approximate missing data can be generated by AI, ensuring that nitrogen management decisions can still be made, even when ideal conditions for data collection are not met.

2. **Multi-source data fusion**: Artificial intelligence can also integrate data from multiple sources, such as drones, satellites, and ground-based sensors, to provide a

continuous stream of information. When satellite imagery is disrupted by cloud cover, data from drone flights or proximal sensors can be fused to maintain a comprehensive view of the field. This integration allows for more robust nitrogen management, even under suboptimal weather conditions.

3. **Predictive nitrogen management**: Historical data can be used by AI-powered systems to predict future nitrogen needs, even when current imagery is unavailable. These models can account for expected rainfall, crop growth stages, and past nutrient applications to forecast nitrogen demand, helping farmers avoid over-application and minimizing the risk of leaching.

4. **Advanced monitoring of multiple nutrients**: Beyond nitrogen, AI can help improve the precision of managing other critical nutrients like phosphorus and potassium by incorporating data from multiple nutrient indices. The combination of NDRE, CI, and other spectral indices enables a more holistic nutrient management system, reducing the risk of both over-fertilization and nutrient imbalances.

Artificial intelligence can also integrate data from multiple sources, such as drones, satellites, and ground-based sensors, to provide a continuous stream of information. Illustration courtesy of Adobe Stock/REI.

Even though the large language models (LLMs) can help in addressing some challenges, they cannot replace the need for field scouting or ground truthing. The imagery can help us identify blocks in the field that show deficiency symptoms and that might need attention, but it cannot tell the difference between nitrogen and sulfur deficiency or between insect infestation or hail damage. I got to see this in western Nebraska in a field that was badly impacted by strong winds and hail, and by only relying on satellite imagery, it would have been impossible to guess.

Conclusion

Imagery-based nitrogen management systems offer tremendous potential for improving the efficiency of nitrogen use in agriculture. However, challenges such as cloud cover, image quality, and nitrogen leaching must be addressed for these systems to reach their full potential. Solutions driven by AI, combined with better agronomic practices, can help mitigate these challenges and reduce the environmental impact of nitrogen leaching, particularly in nitrogen-intensive regions.

Self-study CEU quiz

Earn 0.5 CEUs in Nutrient Management by taking the quiz for the article at https://web.sciencesocieties.org/Learning-Center/Courses. For your convenience, the quiz is printed below. The CEU can be purchased individually, or you can access as part of your Online Classroom Subscription.

1. **Which of the following are challenges to imagery-based crop nitrogen management?**

   a. Cloud cover.

   b. Hazy atmosphere.

   c. None of the above.

   d. Both a and b.

2. **What does NDRE stand for?**

   a. Normalized difference red event.

b. Normalized difference red edge.

c. Nitrogen difference red edge.

d. Nitrogen difference red event.

3. **NDVI differs from NDRE in that it operates in the red-edge region of the light spectrum.**

   a. True.

   b. False.

4. **Nitrogen leaching**

   a. leads to increased input costs and yield gains.

   b. occurs when NH_4^+ moves beyond the root zone due to excessive rainfall or irrigation.

   c. can lead to drinking water contamination, resulting in health risks for infants.

   d. Both a and b.

5. **Which of the following is NOT among the ways mentioned in the article that artificial intelligence can help farmers avoid over-application of nitrogen fertilizers?**

a. Detecting and removing nitrogen from the soil.

b. Combining and incorporating data from multiple nutrient indices.

c. Predicting the state of the crops beneath cloud cover, using historical data and weather patterns to fill in gaps.

d. Accounting for expected rainfall, crop growth stages, and past nutrient applications to forecast nitrogen demand.
