Incorporating Risk into 4R Nutrient Management Decisions

Peter Kyveryga, Operation Manager-Analytics; Pat Reeg, Director of On-Farm Network, and Tristan Mueller, Operation Manager-Agronomic Research, On-Farm Network, Iowa Soybean Association; Chris Anderson, Research Assistant Professor, Agronomy Department, Iowa State University

Introduction

A substantial amount of the uncertainty and unpredictability related to corn nitrogen (N) management across the Midwest can be attributed primarily to several common risk factors: (1) environmental losses of N to water or air, (2) economic penalties from over or under applications of N, and (3) difficulties of quantifying the supply of nitrogen available from the soil, and therefore, making adjustments for in-season weather. Rainfall plays a crucial role in controlling all of these risk factors, but its effects on N management are difficult to quantify when making management decisions for unobserved or future situations.

Another complication in N management in Iowa is that farmers historically use practices with different timings, various application methods and several N fertilizer sources or forms. The combination of these factors makes developing N recommendations for all of these practices extremely difficult. The renewed focus on 4R management– the right source, right rate, right timing and right placement– require adjustments for these differences among practices under site-specific conditions (IPNI, 2012).

Research about N management in corn has rapidly advanced during the last 10 years by adopting regional N recommendations based on yield response and profit optimization (Sawyer et al., 2006) or by using in-season N diagnostics tools such as chlorophyll meters or crop canopy sensors (Scharf and Lory, 2002; Holland and Sheperds, 2010).

The process of making N recommendations involves making predictions for the future, and this means fertilizer recommendations should be expressed as ranges with some attached probabilities. Not only is future weather inherently uncertain, but there is also unaccounted spatial and temporal variability in yield response to N. To estimate these probabilities, researchers need a large number of observations over a large geographic area and across multiple years.

One way to quantify the risks involved in N management is to collect, aggregate and analyze feedback information from a large number of farmers' fields over time. These annual assessments can be used to quantify the effect of rainfall on corn N status or the likelihood of yield response to N fertilizer. This approach is called adaptive management or participatory learning. Farmers participating in local groups or networks can help collect information needed to quantify the risk.

The objective of this article is to describe a survey approach based on late-season feedback about corn N status to quantify the risk of deficient or excessive corn N status in farmers' fields with different forms and timing of N application under variable amount of in-season rainfall observed across Iowa.

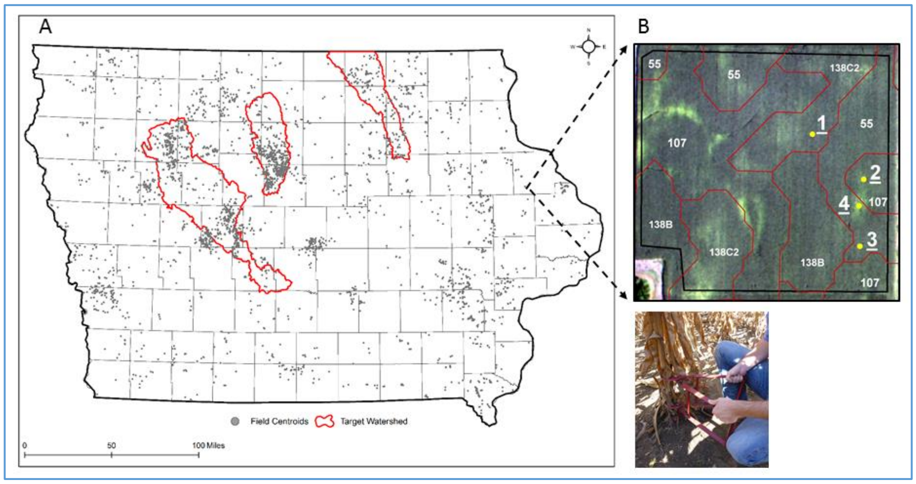

Figure 1. (A) Locations of 3,430 corn fields evaluated for post-season corn N status during a period from 2006 through 2013. (B) The digital color aerial imagery of the corn canopy was used to select three sampling areas (1, 2, and 3) within three predominant soil types to characterize the average field N status. Corn stalk sample 4 was collected within a target deficient area that looked deficient or yellow. Observations from sampling area 4 were not used in analyses of this study.

Methods

Observations of late-season corn N status were collected from about 3,430 corn fields using the late-season corn stalk nitrate test (CSNT) (Blackmer and Mallarino, 1996) and were guided by digital aerial imagery of the corn canopy (Figure 1A). The data from the 2006, 2007 and 2008 studies have been published in peer-reviewed literature (Kyveryga et al., 2011; Kyveryga et al., 2012). The North Raccoon, Boone and Upper Cedar Watersheds were used in the 2013 survey in Iowa (Adaptive Management Publication, 2014).

In general, the data collection process was similar across all these studies and it was designed to evaluate field-average and stressed areas. To select sampling areas for the CSNT, color digital aerial imagery (red, green, and blue bands) was overlaid with a digital soil map to select four CSNT sampling locations within each field (Figure 1B). Three corn stalk samples were collected within three predominant soil types (based on their area within the fields) to characterize the field-average N status. The fourth sample was collected within the area that appeared to be the most N deficient, with lighter or less green or more yellow color of corn canopy. This target deficient sample was collected to confirm that the more yellow color (less plant chlorophyll concentration) of corn canopy was associated with N deficiency but not with other plant stresses such as drought or excessive soil moisture, herbicide injury or early corn senescence.

Stalk samples were collected from two to five weeks after corn grain reached physiological maturity or black layer stage. Ten 8-in stalk segments 6-in above the ground were cut within each sampling area (Blackmer and Mallarino, 1996) that included two corn rows extending for about 30-40 ft. The collected samples were analyzed for stalk NO_3-N concentrations with a Lachat flow-injection analyzer (Lachat Instruments, Milwaukee, WI).

The late-season CSNT was developed to diagnose N sufficiency (i.e., N supply relative to N demand) or corn N status (Blackmer and Mallarino, 1996). The test results are reported as four NO_3-N sufficiency categories: deficient (<250 mg kg^{-1}), marginal (250-700 mg kg^{-1}), optimal (700-2000 mg kg^{-1}), and excessive (>2000 mg kg^{-1}).

- Deficient; low N available (soil or fertilizer) results in likely economic yield loss.
- Marginal; economic yield responses from additional N applications would be equally likely.
- Optimal; N supply matches corn N demand so that and yield response to additional N is unlikely or equally likely.
- Excessive; N supply exceeded the plant demand and the yield response to additional N is unlikely.

CSNT data were aggregated as N sufficiency categories because nitrate concentrations are extremely skewed and because CSNT was developed to provide categorical expression of late-season corn N status.

Spatially interpolated monthly average rainfall data (4-km grids) were downloaded from the Iowa Environmental Mesonet, Agronomy Department, Iowa State University (http://mesonet.agron.iastate.edu/). Each field was assigned a rainfall value from a rainfall grid located nearest the field sampled.

The agronomic risk of deficient or excessive corn N status was determined through simplifying the four stalk nitrate test categories (Deficient, Marginal, Optimal and Excessive) into two pairs of binary categories: “Deficient vs Sufficient” and “Excessive vs Sufficient & Below”. Mixed effects logistic regression analysis was applied to quantify risk factors for Deficient or Excessive N status. In this analysis, the field effect was considered as random, allowing interpretations for a range of fields across Iowa.

Several factors were evaluated when determining the best models for agronomic risk of Deficient or Excessive corn N status: (1) monthly or different combination of cumulative monthly rainfalls (e.g, cumulative summer, spring or growing season); (2) total N rates applied, (3) previous crop (C-C, corn after corn and C-S, corn after soybean), (4) N management categories expressed as a combination of N form and timing of application (Fall AA; fall-applied anhydrous ammonia; Fall SM, fall-injected liquid swine manure; SD UAN/AA, sidedress anhydrous ammonia or UAN; Spring AA, spring applied anhydrous ammonia; Spring UAN, spring-applied UAN), (5) year and (6) several possible interaction between continuous and categorical covariates.

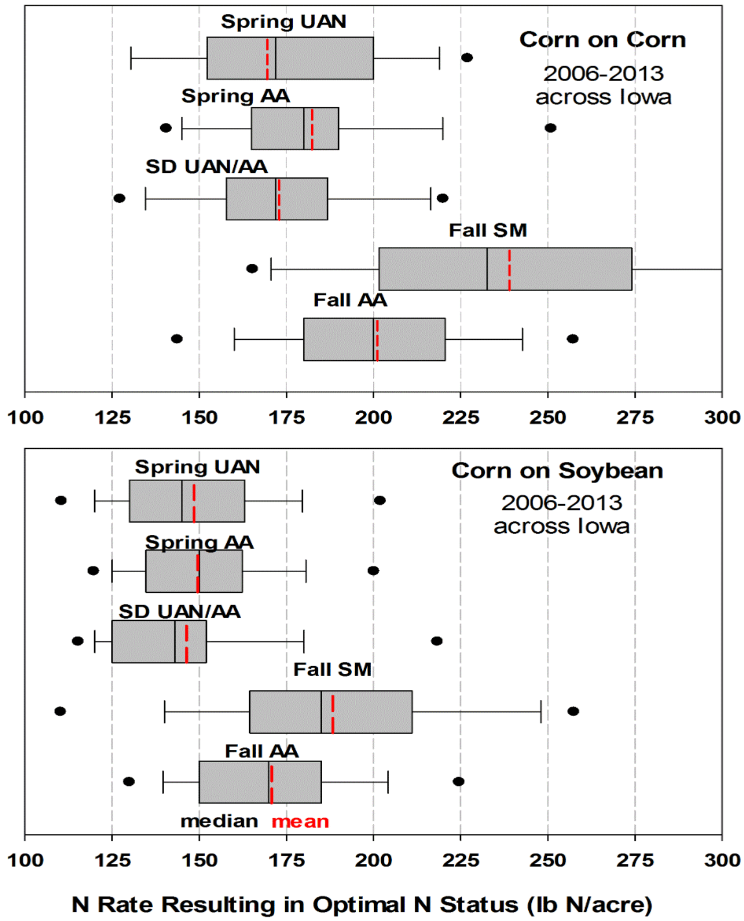

Figure 2. Distribution of N rates used by farmers to reach the optimal corn N status for different N management categories from 166 corn after corn (C-C) and 465 corn-after-soybean (C-S) fields evaluated across Iowa from 2006 through 2013. The boxes indicate the 25th and 75th percentiles; the black vertical lines, medians; the red vertical lines, averages, and whisker bars indicate the 5th and the 95th percentile. Predominant N forms and timing of application: AA Fall =fall-applied anhydrous ammonia; Fall SM=fall-injected swine manure; SD UAN/UAN=sidedress urea ammonium nitrate solution or anhydrous ammonia; Spring AA=spring-applied anhydrous ammonia; Spring UAN=spring-applied UAN.

Benchmarking Rates That Resulted in Optimal N Status

Distributions of N rates that resulted in optimal field-level N status are shown in Figure 2. These distributions are based on data from 166 corn-after-corn and 465 corn-after-soybean fields evaluated across Iowa from 2006 through 2013.

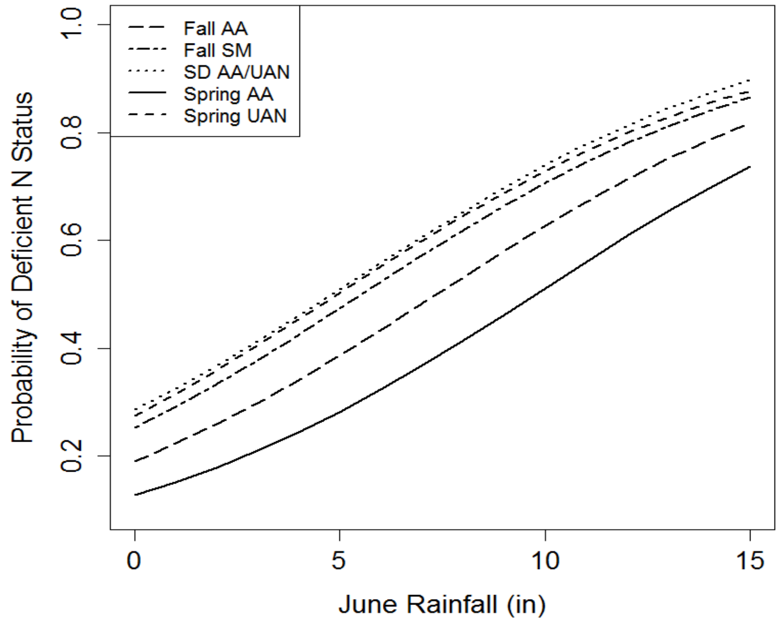

Figure 3. Effect of June rainfall on the probability of deficient N status for corn-after-soybean (C-S) fields with 150 lb N/acre for practices with different timing and N fertilizer forms. Fall AA=fall-applied anhydrous ammonia; Fall SM=fall-injected swine manure; SD UAN/UAN=sidedress urea ammonium nitrate solution or anhydrous ammonia; Spring AA=spring-applied anhydrous ammonia; Spring UAN=spring-applied UAN

For both C-C and C-S, fields using Fall AA and Fall SM required slightly higher rates to reach the optimal N status; whereas, fields with Spring UAN, Spring AA, SD N (UAN or AA) required lower amount of N. The field-level variation in N rates was larger for Fall SM than for other practices (Figure 2; grey boxes). The larger rates required to reach the optimal N status for Fall SM could be due to larger uncertainty in quantifying the exact amount of N applied with the manure or difficulty adjusting N rates for percentage of N available from manure during the growing season.

For C-C compared to C-S, the difference between N rates resulting in the optimal N status was on average ~25 lb N/acre higher.

Predicting Agronomic Risk of Deficient N Status

The best model for predicting the agronomic risk of deficient N status included four factors: June rainfall, total N rate applied, previous crop, and N management (a combination of timing and form of N application). An increase in June rainfall by 1 inch, holding all other factors constant, increased the probability the deficient N status on average by 21%, with the 90% confidence interval (90% CI) from 18 to 25%. The increase in N rate by l lb/acre has decreased the probability of deficient status approximately by 1%. And corn-after-soybean fields were on average 37% (90% CI; from 9 to 72%) more likely to be deficient than those planted after corn.

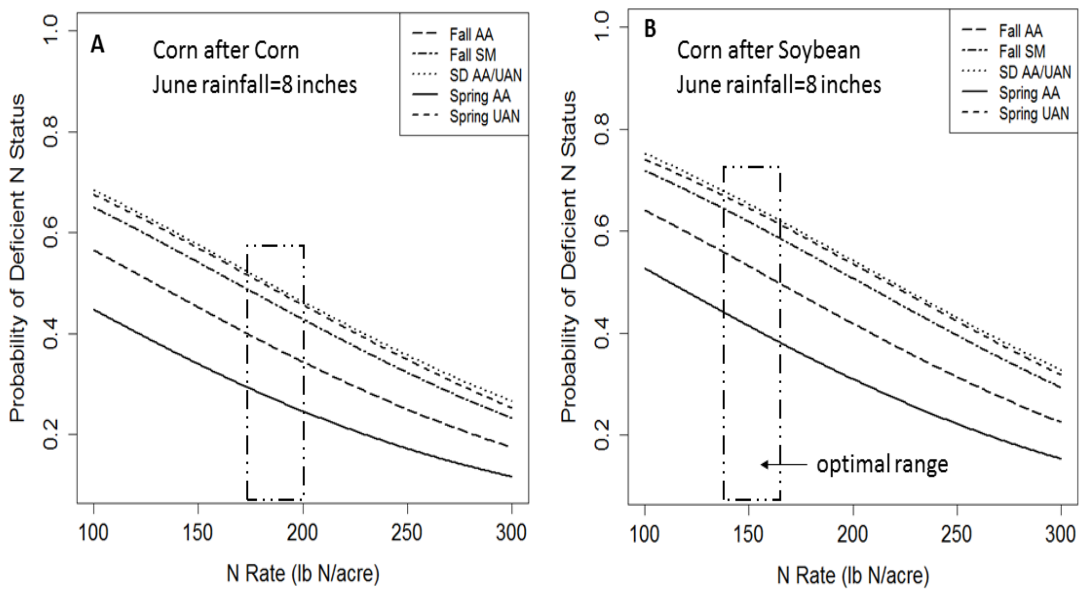

Figure 4. Simultaneous effect of N rate, crop rotation, and N Management on the probability of deficient N status for fields receiving twice the normal rainfall in June. Predominant N forms and timing of application: Fall AA=fall-applied anhydrous ammonia; Fall SM=fall-injected swine manure; SD UAN/UAN=sidedress urea ammonium nitrate solution or anhydrous ammonia; Spring AA=spring-applied anhydrous ammonia; Spring UAN=spring-applied UAN.

Similarly, holding all other factors constant, fields with Fall SM were more likely to be deficient by 43%; SD UAN by 36% and Spring UAN by 41% than fields with Fall AA. The risk of deficient N status was the lowest for Spring AA.

The predicted effect of June rainfall and N management on the risk of deficiency at a fixed N rate of 150 lb N/acre for corn after soybean is shown in Figure 3. Corn fields that received Spring AA had the lowest risk of deficient N status, in contrast, applications of Spring UAN and SD UAN/AA had the highest risk. Comparing an optimal N range for C-S (150 lb N acre) and for C-C (180 lb N/acre), we find under the same amount of rainfall that C-S fields rather than C-C fields have higher risk of deficient N status (Figure 4).

The positive correlation of June rainfall with the risk of N deficiency can be explained by a higher tendency of N losses with more rainfall and/or by the increased demand in N due to higher corn yield potential during years with above normal rainfall.

Table 1. Estimated probability of deficient corn N status for five management practices for corn after soybean when June rainfall is below normal, normal or above normal. Risk interpretations were very low (0-0.30), low (0.31-0.50), moderate (0.51-0.60), high (0.61-0.80) or very high risk (0.81-1.0).

Total N rate (lb/acre)	June Rainfall		
	Below Normal, 2 inches	Normal, 4 inches	Excessive, 8 inches
	Fall AA		
100*	0.36	0.44	**0.64**
130	0.29	0.38	**0.58**
150	0.26	0.34	**0.53**
160	0.24	0.32	**0.51**
	Fall SM		
100*	0.45	**0.54**	**0.71**
130	0.38	0.47	**0.66**
150	0.33	0.43	**0.62**
160	0.31	0.36	**0.55**
180	0.28	0.36	**0.55**
	Spring AA		
130	0.21	0.28	0.46
150	0.18	0.24	0.41
160	0.16	0.23	0.40
	Spring UAN		
130	0.40	0.50	**0.69**
150	0.36	0.45	**0.65**
160	0.34	0.43	**0.62**
	SD UAN/AA		
100*	0.44	**0.54**	**0.72**
130	0.37	0.48	**0.67**
150	0.34	0.43	**0.62**
160	0.32	0.41	**0.60**

* below optimal rates or rates that fall below the 25th percentile in Figure 3.
Bold numbers indicate either moderate (0.51-0.60), high (0.61-0.7-80) or very high risk (>0.81) of deficient N status.

Predicting Agronomic Risk of Excessive N Status

The best model for predicting the agronomic risk of excessive corn N status also included four factors: cumulative April through June rainfall, total N rate applied, previous crop, and N management (a combination of timing and form of N application). An increase in April through June rainfall by 1 inch, holding all other variables constant, has decreased the probability of excessive N status by 9%, with a 90% CI from 7 to 10%.

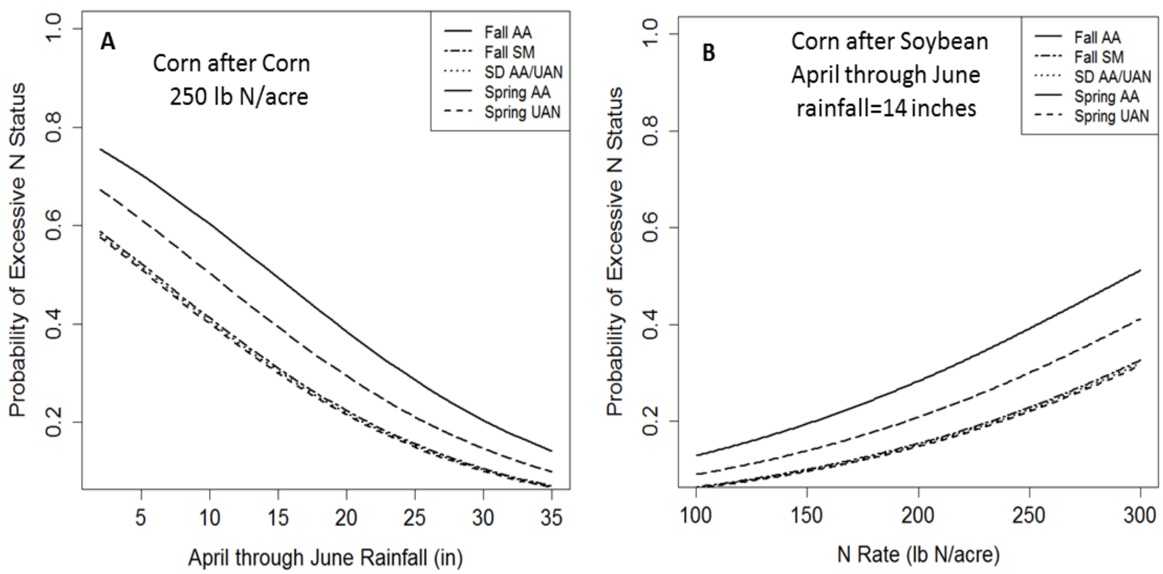

Figure 5. Simultaneous effect of N rate, April through June rainfall, N Management on the probability of excessive corn N status for fields across Iowa for corn and after corn and corn after soybean. Predominant N forms and timing of application: Fall AA =fall-applied anhydrous ammonia; Fall SM=fall-injected swine manure; SD UAN/UAN=sidedress urea ammonium nitrate solution or anhydrous ammonia; Spring AA=spring-applied anhydrous ammonia; Spring UAN=spring-applied UAN.

By comparison, an increase in N rate by l lb/acre has increased the probability of excessive N status by less than 1%. C-C compared to C-S fields were on average 80% more likely (90% CI; 49-219%) to have excessive N. Fields with Fall SM, SD UAN/AA or Spring UAN were less likely to be excessive than those applied with Fall AA (Figure 5A and B).

Practical Use of Estimated Risk Values

The estimated probability of deficient or excessive N status can guide developing before season N management plans or the need for additional N application within season. A risk matrix can be developed for N rate guidance by assigning the following risk categories to probability ranges for N deficiency: very low risk (0.0 to 0.30), low risk (0.31 to 0.50), moderate risk (0.51 to 0.60), high risk (0.61 to 0.80) or very high risk (0.81 to 1.0).

Table 1 is an example of a risk matrix for N deficiency in C-S fields based on June rainfall. The grower identifies the set of rows for N source, the row for N rate, and column for June rainfall. For instance, prior to the growing season, a grower can choose a moderate risk of N deficiency by planning to apply 130 lb/acre of Spring UAN and assuming average June rainfall (Column 2). In season, if June rainfall is normal or below, the grower can be confident the risk of N deficiency has either remained unchanged (Column 2) or decreased (Column 1), but if June rainfall is above normal (Column 3) the grower can see a change in N deficiency risk category from moderate to high.

Additionally, if a farmer should decide N deficiency risk is too high, the likelihood for profitable yield response if a farmer should apply additional N can be determined. For example, should above average June rainfall shift in-season N deficiency risk from moderate to high, a grower may consider supplemental N application of an additional N. Previous on-farm trials with farmers' normal and N rates that were 30% below or above the normal levels showed that the probability of break-even yield response to additional 50 lb N/acre was within a range of 0.60 to 0.70 (Kyveryga and Blackmer, 2012).

Summary

This feedback-based approach using feedback from farmers' fields and weather monitoring enable growers and agronomists to quantify the risk of deficient or excessive corn N status. This process, "annual N check-up", engages growers and agronomists in dynamic, participatory learning about complex effect of farmer N management practices and rainfall variability factors on the risk of deficient or excessive corn N status. The feedback-based approach from on-farm evaluations can be used in nutrient, manure management or 4R management planning. The estimated risk values of deficient or excessive corn N status can be used to play various before season and in-season "if what scenarios" for different amount of observed or historical rainfall for a given area or field in Iowa.

Acknowledgment

Studies described here were partially funded by the United State Department of Agriculture Natural Resource Conservation Services (NRCS) Grants, NRCS Nutrient Adaptive Management Project, Integrated Farm Livestock Management Project from the Soil Conservation Division of the Iowa Department of Agriculture and Land Stewardship, Iowa Soybean Association Checkoff dollars. We are very thankful to all farmers, agronomists, technical providers, industry professionals, and partner university scientists who participated and contributed to the on-farm studies described in this publication.

References

Adaptive Nitrogen Management: Post-season evaluations of farmers' management practices to improve nitrogen use in corn production. 2014. Iowa Soybean Association. www.isafarmnet.com/AdaptiveNitrogenManagement%20/Adaptive_Nitrogen_Management_2014.pdf.

Blackmer, A.M., and A.P. Mallarino. 1996. Cornstalk testing to evaluate nitrogen management. Iowa State Univ. Ext. Bull. Pm-1584., Ames, IA.

Holland, K.H, and J.S. Schepers. 2010. Application model for in-season fertilization of corn. Agronomy J. 102:1415-1424.

IPNI. 2012. 4R Plant Nutrition Manual: A Manual for Improving the Management of Plant Nutrition, International Plant Nutrition Institute, Norcross, GA.

Kyveryga, P.M., T.M. Blackmer, and R. Pearson. 2012. Normalization of uncalibrated late-season digital aerial imagery for evaluating corn nitrogen status. Preci. Agric. 13:2-16. DOI 10.1007/s11119-011-9231-8.

Kyveryga, P.M., and T.M. Blackmer. 2012. On-farm evaluations to calibrate tools for estimating late-season nitrogen status of corn. Agronomy J. 104:1284-1294

Kyveryga, P.M., T.M. Blackmer, R. Pearson, and T.F. Morris. 2011. Late-season digital aerial imagery and stalk nitrate testing to estimate the percentage of areas with different N status within fields. J. Soil Water Cons. 66:373-385.

R Development Core Team. 2004. R: A language and environment for statistical computing.

Sawyer, J., E. Nafziger, G. Randall, L. Bundy, G. Rehm, and B. Joern. 2006. Concept and rationale for regional nitrogen rate guidelines for corn. Iowa State Univ. Ext. Ames. IA www.extension.iastate.edu/Publications/Pm2015.pdf.

Scharf, P.C., and J.A. Lory. 2002. Calibrating corn color from aerial photographs to predict sidedress nitrogen need. Agron. J. 94:397-404.