United States Department of Agriculture
Natural Resources Conservation Service

Agronomy Technical Note No. 7

May 2013

Adaptive Nutrient Management Process

Issued May 2013

Cover photo:

Application of anhydrous ammonia fertilizer at planting time.
Photo by Lynn Betts, NRCS.

USDA prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex (including gender identity and expression), marital status, familial status, parental status, religion, sexual orientation, political beliefs, genetic information, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.)

To file a complaint of discrimination, complete, sign and mail a program discrimination complaint form, available at any USDA office location or online at www.ascr.usda.gov, or write to: USDA, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410, or call toll free at (866) 632-9992 (voice) to obtain additional information, the appropriate office or to request documents. Individuals who are deaf, hard of hearing, or have speech disabilities may contact USDA through the Federal Relay service at (800) 877-8339 or (800) 845-6136 (in Spanish). USDA is an equal opportunity provider, employer and lender.

Persons with disabilities who require alternative means for communication of program information (e.g., Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).

Adaptive Nutrient Management Process

Introduction

Climate, fertilizer costs, supply and demand, international market influences, and commodity prices are major factors that influence, and often complicate or compromise, a grower's ability to maximize profit in any given year. This technical note offers an adaptive management approach that will enable growers to use a data-driven process to refine nutrient management to better adapt to conditions encountered on their farms. The adaptive management approach can promote better nutrient use efficiency on individual farms or throughout farming communities by means of systematic and user-friendly evaluations of nutrient practices. The approach is most effective when multiple farms evaluate one practice.

Managing nutrients is critical to producers because it affects productivity and profitability and can have natural resource consequences both on and off the farm. Nutrients, especially nitrogen (N) and phosphorus (P), have multiple potential loss pathways in agricultural systems. The rate and magnitude of nutrient losses are influenced by a variety of factors that can interact with each other, including weather, management practices, and soil types. Difficult to resolve is the fact that the optimum rate of N for a given field can vary from year to year by more than 60 pounds (lbs) per acre due to weather and other factors. Consequently, there is no single nutrient management strategy that can be considered optimal for all cropping scenarios.

Traditionally, nutrient management strategies have been based on a generalized recommendation approach. Typical recommendation sources include university fertilizer recommendations (sometimes called "best management practices") or other guidelines that have been compiled to develop an estimate of nutrient needs based on past data collected and documented field experience. Although relatively simple, this process does not explicitly incorporate a process for evaluating and verifying the performance of the recommendation on an individual field or farm or make adjustments to improve performance and efficiency. Without a structured process to verify and improve performance, a farmer's ability to know how to refine their management to protect natural resources or to optimize nutrient use efficiency and profit is limited. Under the generalized recommendation strategy, future recommendations are not changed until the need becomes apparent to the technical expert developing and evaluating the recommendation. Because optimum N rates for individual fields can vary considerably from the average rate for many fields, this delay can result in a repetitive cycle of unnecessary inputs and lower profits due to inefficient nutrient use.

The adaptive nutrient management approach can be used to—

- Improve the nutrient use efficiency.
- Decrease the loss of nutrients to the environment while maintaining or increasing yields.
- Evaluate the effectiveness of new nutrient management technologies.
- Test and evaluate the performance of new tools or techniques for nutrient management.
- Evaluate postseason site-specific data that can be used to establish future optimal nutrient applications.
- Establish groups of farmers who cooperate with nutrient management specialists to learn from results of evaluations on their farms.

Definition of Adaptive Nutrient Management

Adaptive nutrient management is a process used to evaluate and adjust nutrient application and utilization strategies over multiple seasons. The process allows for continued adjustments of the NRCS-assisted Conservation Practice Standard (CPS) Code 590, Nutrient Management, to achieve better nutrient use efficiency. Adaptive nutrient management promotes the coordination of amount (rate), source,

timing, and placement (method of application) of plant nutrients to minimize nutrient losses.

CPS Code 590, Nutrient Management, and the Adaptive Nutrient Management Process

State-approved adaptive nutrient management activities are considered in compliance with the operation and maintenance requirements of the CPS Code 590, Nutrient Management, and Step 9 of Title 180, National Planning Procedures Handbook (NPPH), Part 600, Subpart A, Section 600.11, "The Planning Process."

The Adaptive Management Process – Plan, Review, Learn, Adapt

Adaptive nutrient management is systematic processes to collect, analyze, and learn from results of evaluations of nutrient practices conducted on farmers' fields. The goal of planning in nutrient management is to coordinate the amount, source, placement, and timing of nutrient applications to protect the environment, lower production costs, and maximize the realized profit from each field or subfield. While all nutrient management plans involve initial planning or predicting, most involve only implementation of the plan and do not include a systematic evaluation component. Adaptive nutrient management differs by explicit and systematic incorporation of the evaluation as part of the planning process, then learning from the results to improve management in current and future years.

Adaptive nutrient management requires evaluation at least once a year when a crop is harvested. If in-season adaptive management tools are used, the evaluation occurs at least twice a year, when a soil or plant tissue test is completed and when a crop is harvested. The most critical review of a nutrient management plan takes place during the winter, when farmers meet as groups or one-on-one with an advisor to discuss the results of the evaluations and ways to adapt management in the next season to increase efficiency.

How the Adaptive Nutrient Management Process Works

Adaptive nutrient management is a process for evaluating and adjusting nutrient management based on data collected at the field level following a set of protocols. Adaptive management (fig 1) can help producers make better nutrient management decisions leading to reduced nutrient inputs, higher yields, increased profits, and improved environmental benefits such as water quality.

Four basic steps are involved:

Step 1 Develop the plan for the evaluation.

Step 2 Implement the nutrient management plan.

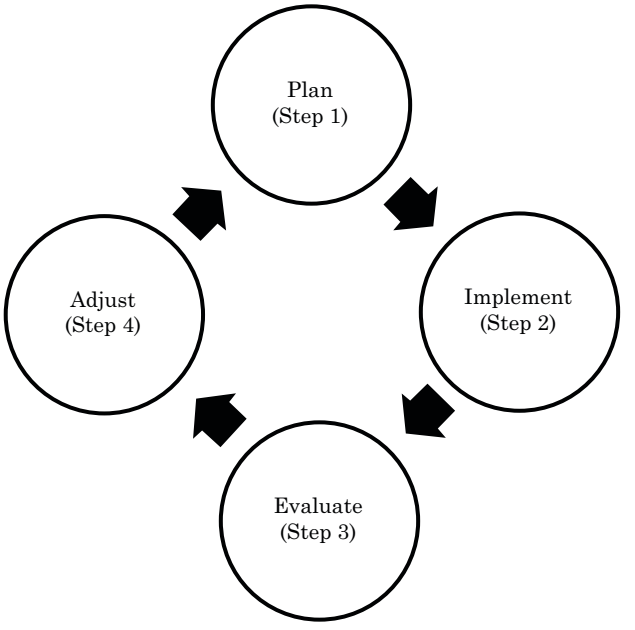
Step 3 Evaluate the plan based on lessons learned.

Step 4 Adjust the nutrient management.

Adaptive Nutrient Management Process

Adaptive nutrient management is an ongoing evaluation and learning process. Specifically, adaptive nutrient management tailors nutrient management for the grower's unique farming operation. The evaluation also helps growers to better tailor conservation practices that are best suited to their operations to address identified natural resource concerns.

Figure 1 Adaptive nutrient management process



Adaptive Nutrient Management Protocol

To make meaningful adaptive nutrient management decisions, a grower needs reliable data. The following is a how-to guide for farmers and professionals relating how to implement the adaptive nutrient management process. This protocol provides—

- A process and the guidelines for making objective evaluations.
- A process for learning from the results of the evaluations.
- Guidance relating how the adaptive nutrient management process can be used to evaluate new nutrient strategies.

Growers can use on-farm field trial procedures to evaluate various nutrient rates, timing, sources, and methods of application. By following the on-farm field trial procedures in this document, growers can objectively conduct a field trial on their land, interpret the results, and make adaptive management changes to their nutrient management strategy. These same on-farm field trial techniques can also be used to evaluate other management changes such as seeding rates, hybrid selection, tillage systems, cover crops, weed and pest control, etc.

On-farm field trial comparisons need to be carefully planned to produce credible results. A simple side-by-side comparison of two different management systems will not provide the credible data needed to make informed decisions regarding changes in future management. Reliable data are also important to document changes across years in support of longer term nutrient planning.

Conducting on-farm field trials requires—

- Developing a hypothesis—"If I make this change, I expect these results."
- Planning of replicated plot trials.
- Determining the resources needed to carry out the plot trials.
- Measuring or "laying out" the replicated plot trials in the field.
- Collecting data important to evaluation of your hypothesis.
- Analyzing the data collected (may involve preseason, in-season and postseason data).
- Summarizing of the data and conclusions.

Step 1 Develop the hypothesis:

Example hypothesis: Lowering my N rate by 30 lbs N/acre will not decrease yield.

Step 2 Plan the replicated plot trials:

The plots must be randomized to minimize the bias contributed by differing soils, topography, pest infestations, etc., that may be present on one plot and not another.

Plot trials should have at least four replications. The minimum is three for confident analyses. Four replications increase the ability to detect changes due to treatment differences. Additionally, the fourth replication allows for the loss of one plot due to weather damage, pest problems, etc. Each treatment or plot in the replication is harvested and weighed separately. The harvest weights for each treatment and replication are then averaged and the treatments are compared. The typical layout for a comparison for two treatments would look like the example in table 1.

Table 1 Plot trial with two treatments replicated four times

Replication 1		Replication 2		Replication 3		Replication 4	
B Treatment	A Treatment	A Treatment	B Treatment	A Treatment	B Treatment	B Treatment	A Treatment

Because of variations in year-to-year weather, pest problems, etc., the replicated plots should be conducted for at least 3 years to properly account for these variations. The reliability of the data can also be enhanced by increasing the number of identical plot trials. One way is to partner with neighbors who would evaluate the same variables on their farms having similar management systems and soils. This also increases the learning that occurs through the sharing of results, evaluations, and discussion of adjustments they may consider.

Individual plots should be planned to accommodate the width of the planter, fertilizer applicator, and harvesting equipment to be used. Typically, a plot width is twice the width of the harvest equipment.

Step 3 Determine the resources needed to carry out the plot comparisons.

Consider the following:

- The equipment must be capable of delivery of planned amount, source, placement, or timing of the planned treatments for each plot.
- The materials to be used to identify the boundaries of each plot. Markers should be easily found and identifiable throughout the season. A plot map should clearly indicate the boundaries and treatments applied.
- GPS requirements, if used.
- Calibrate the application equipment, harvesting equipment, weigh wagons, etc.
- Plan for the proper equipment to accurately measure yield, moisture, etc.
- Determine the need for supplies associated with record keeping, recording, or evaluating data.
- Plan for the required analysis of plot results, including an evaluation of least significant difference (LSD). You may need consultant or university expert assistance to properly analyze the data collected.

Step 4 Lay out the replicated plots.

- The replicated plots must be laid out in widths (typically, the most limiting piece of equipment) that will facilitate the planting, harvesting, nutrient application, and other equipment used on the plots.
- The plots should be laid out where soils, fertility, slope, and drainage are as uniform as possible.
- Clearly stake out and mark all treatments. Do not rely on memory. GPS can be used in addition to markers to document treatments.

Step 5 Collect the data.

- Record the date of planting, amount, source, placement, and time of nutrient applications, pesticide applications, pest activity, and weather. Also record other observations that may impact plot performance (e.g., lodging, plot damage due to animals, etc.). This will help in the final analyses of the data.
- Ensure harvest yield measurement equipment is properly calibrated (includes combine yield monitors, weigh wagons, moisture testers, etc.)
- Make plans before harvest on how the data will be recorded. It is best to develop a form that can be used to record all the data completely and uniformly.
- Record the data in the planned format at the time of measurement.

Step 6 Analyze the data.

Quick observations of yield data without statistical analyses of the data can lead to false conclusions. The data collected from the replicated plots must be analyzed to determine where differences in treatments received were meaningful (significant). The LSD tool is often used to evaluate significant differences when plot yield results are compared.

Tables 2 and 3, and the following procedure are adapted from the "On-Farm Research Guidebook" (Anderson 1993) (Available at: http://www.aces.uiuc.edu/vista/abstracts/aGUIDEBK.html). These calculations illustrate how to record data and calculate the LSD.

To record and calculate the LSD (see table 2, sum of squares worksheet):

Step 1 Calculate the variance.

$$\text{variance} = \frac{D^2_{\text{total}}}{r-1}$$

where

r = number of repetitions

D^2 total = 18.0

$(r - 1 = (4 - 1) = 3$

$$\frac{18.0}{3} = 6.0$$

Step 2 Calculate the variance of the means = variance ÷ r.

$$\frac{6.0}{3} = 2.0$$

Step 3 Calculate the standard error – standard error = square root of the variance of the means.

$$\sqrt{2} = 1.41$$

Step 4 Calculate the least significant difference (LSD).

(a) Multiply the standard error in step 3 above by the appropriate t-value.

(b) Appropriate t-value (confidence level) found in table 3.

(c) Use t-value = 3.18 (use an alpha of 0.05)

$$1.41 \times 3.18 = 5.37 = \text{LSD}$$

(d) Compare the LSD to the C average in table 2 = -8.0. Ignore the negative value. Since the C average of 8.0 is more than the LSD of 5.37, then the observed difference is significant at the alpha level of 0.05 for the B treatment (150 lbs N applied).

Step 5 Application (Conclusion).—Lowering my N rate by 30 lbs N/acre did not reduce yield.

Table 2 Example of worksheet (sum of squares calculation) (Anderson 1993)

	Treatments		Difference (C)	Deviation (D)	Deviation squared (D^2)
Blocks (r)	A 180 lbs N* fall	B 150 lbs N*	C = A – B	D = C – C average	$D^2 = D \times D$
I	141	152	-11	-3.0	9.0
II	147	156	-9	-1.0	1.0
III	149	155	-6	2	4.0
IV	151	157	-6	2	4.0
Totals	588	620	-32		D^2 total = 18.0
Averages	A = 146.5	B = 153.3	C = –8.0		

* N=Nitrogen

Table 3 Appropriate T-values

	T-Values		
Number of reps (r)	Alpha 0.05	Alpha 0.10	Alpha 0.30
2	12.71	6.31	1.96
3	4.30	2.92	1.39
4	3.18	2.35	1.25
5	2.78	2.13	1.19
6	2.57	2.02	1.16
7	2.45	1.94	1.13
8	2.37	1.90	1.12
9	2.31	1.86	1.11
10	2.26	1.83	1.10

Tools for In-Field Evaluations for N

The following provide technical guidance for some key adaptive management tools:

- Replicated plot trials: Growers can use on-farm field trial procedures to evaluate various nutrient rates, timing, sources, and methods of application. By following the on-farm field trial procedures in this document, growers can objectively conduct a field trial on their land, interpret the results, and make adaptive management changes to their nutrient management strategy. These same on-farm field trial techniques can also be used to evaluate other management changes such as seeding rates, hybrid selection, tillage systems, cover crops, weed and pest control, etc.
- The pre-sidedress soil nitrate test (PSNT): Enables producers to estimate the amount of N available in the soil before corn plants begin taking it up intensively. The PSNT can be used to predict which fields might need additional side-dress N. The PSNT is most useful for systems using manure as a source of nutrients.
- Leaf tissue test: An indicator of the amount of N that has been taken up by the plant at that particular moment. This tool can help guide in-season fertilization changes, but cannot detect or predict N stress that may occur later in the season.
- Chlorophyll meters: N stress in a corn plant results in reductions of chlorophyll throughout the plant, which can be detected by a chlorophyll meter. A chlorophyll meter reading provides a snapshot of the N status at the time of sampling.
- Aerial imagery to identify N stress: N stress in corn affects the color of corn leaves and, therefore, the canopy. An aerial image of a field can reveal subtle differences of N stress within a field to a resolution of a single row, and yet can be used to evaluate an entire field.
- End-of-season stalk nitrate testing: Can be used to evaluate the availability of N to the corn crop. Measuring the amount of N that was left in the lower portion of the plant towards the end of the season provides a way to determine whether "extra" N was left in the plant.
- Guided stalk sampling: The variability found in most fields makes it important to consider sample location in the context of the entire field. A technique called guided stalk sampling can give a more accurate picture of the entire field. This strategy combines the information of remote sensing with soil survey information to characterize differences in the field that are likely to change the N availability to the corn crop.
- Crop reflectance sensors: Sensors that measure reflected wavelengths of light related to crop N status. Sensors can be hand-held or tractor mounted. Reflectance indices are used to evaluate crop N sufficiency and adjust the amount of N fertilizer to be applied.

Development of an Adaptive Management Program

The adaptive management process encourages active learning by doing and on discussing new information about ways to improve the current practice either in groups or one-on-one with growers.

There are three general approaches for setting up the learning portion of an adaptive management program. The most effective approach is based on meetings of farmers in groups to learn from the results of the evaluations of their practices. Two other approaches, not as effective as group meetings, but more effective than simply mailing the results of evaluations to farmers, are learning by individual farmers when only their evaluations and field histories are available, and learning by individual farmers when summaries of evaluations and field histories from other farmers in the county, region, or State are available.

Meeting Rationale: Effective Learning for Effective Improvement

Improving nutrient management requires fine-tuning generalized recommendations usually from land grant universities, which results in improvements in the nutrient practices being implemented by the farmers. Both the fine-tuning and the changes involve learning new ideas and having the confidence to apply the new ideas. Learning and making changes are not easy for adults, especially when there is a risk of losing money. Recent advances in adult learning have shown ways to overcome the natural reluctance of adults to move beyond the safety of routine practices. One of the principle findings is that adults learn best when ideas and data are discussed in an interactive format. Traditional lecture and classroom-style training (including agricultural demonstrations and field days) are

highly effective if a problem is well defined (such as information about corn hybrids), but less effective in helping adults develop proficiency in solving problems that are ill-defined and complex, such as nutrient management.

Nutrient management is not well suited to mailing results of evaluations to farmers for a number of reasons. The four primary reasons are as follows:

- There is no one "right" answer to the best rate, form, timing, or placement of nutrient applications.
- Solutions must be developed within the context and resources of farms themselves.
- Learning new approaches often requires "unlearning" old methods.
- Growers need direct, concrete evidence that new methods work.

There are a number of key steps in developing and implementing an adaptive management program: recruitment of farmers, implementation of the adaptive management practice by the farmers, analysis and summary of the data, and farmer discussion meetings and decisions about management changes.

Step 1 Recruit farmers

Adaptive management is a process that is most effective when farmers are connected in a group, learning not only from evaluations from their own farm and fields, but also from other farms in the area. Individual farm data become significantly more meaningful when put in context of evaluations on other farms in the county or watershed. For example, results from a plot trial comparison on one farm are valuable, but it is much more meaningful if a similar comparison is done on five or ten farms in the area.

An ideal group is a "mix" of farmers that will stimulate engaged discussions of nutrient management practices during the annual winter meetings that are a required part of the adaptive management process. This mix should include farmers that are more willing to try new ideas or practices and ones more reluctant. The winter meetings serve as one of the main processes that make adaptive management an effective method for farmers to learn about and then adopt improved nutrient management.

Farmers do not need to be connected in a group for adaptive management to be effective. Meeting with farmers one-on-one also is an effective method for farmers to learn from the evaluations of their practices. The farmers will have more confidence to make changes on their farms if summaries of evaluations completed on farms with identical or similar practices in the same county, region, or State are available. The key to all learning is have the results and field history information summarized for easy understanding and to discuss the information in the context of the farmers' knowledge about their fields and practices.

Step 2 Implement the nutrient management plan and adaptive management practices

After recruiting participants, next identify the practices to be evaluated and the adaptive management tools to be used to conduct the evaluations, gather the necessary baseline information (field-by-field histories of management), and implement the practices identified in the initial nutrient management plan. There are usually two major types of practices implemented in an adaptive management program: 1) a practice that requires close cooperation between the farmer and a farm advisor, such as a plot trial, and 2) a practice that requires minimal cooperation and involvement by the farmer, such as an evaluation of the nutrient status of fields using tools such as soil testing, cornstalk nitrate testing, or aerial imagery.

Step 3 Analyze and summarize data

Collected data must be summarized, analyzed, and presented in a format that gives context and meaning to the farmer. The most effective way to do this is to present the data (for an example of typical data, see Step 5 on page 4) in tables and graphs, which will then be used in the group meetings or when meeting with farmers one-on-one. The tables and graphs should display the data in three ways:

- Geographically.—by farm; by farms in a county, region, or watershed; by farms in a State; and, if two or more States are cooperating, by farm across States.
- According to Management.—grouped by the practices being evaluated.
- Temporally.—by that individual year and cumulatively over multiple years. If one-on-one learning is planned by using results and field histories from only the farmer in the meeting, then only summaries from one farm are needed. A technical advisor familiar with

summarization of data in this manner should create the tables and graphs. The data should be examined for patterns in the assessments to identify categories that can reduce the variability of the assessments. Factors such as previous manure or fertilizer management, the 4Rs of nutrient management (that is, the amount (rate), source, placement (method of application), and timing of plant nutrients and soil amendments), type of manure, tillage, etc., are used to search for categories to reduce variability.

To ensure productive discussions at the annual meetings, the technical advisor who analyzes the data should send a concise hardcopy summary of the assessment results to the farmers and their advisors at least 1 week before the scheduled meeting. The advisor who will be leading the meeting should create and use an effective presentation or handouts to guide the discussion. It is helpful to present the most important results of the assessments, and then to show some individual farm results to engage the farmers in discussion.

Step 4 Conduct discussion meetings

Program coordinators bring the farmers together either in groups or in one-on-one meetings to discuss the results of the assessments. Meetings should be held at a convenient time for the farmers. It is important to have a person who is both knowledgeable about the adaptive management tools and experienced in promoting discussions guide the meetings. The meetings should focus discussion on the categories of management shown by the assessments to have the greatest effect on nutrient efficiency in the field. Things to remember when planning meetings:

- Meeting Format.—There are various ways to set up the groups to encourage discussion. Groups can be composed of farmers with similar knowledge about the test used for the assessment. This is effective because in the first year meeting much of the discussion is often about understanding the rationale for the test used in the assessments. In the second year, the discussion shifts to discussion about categories of data and what improvements can be made for more efficient nutrient management. Two other ways to set up groups are by geographic area such as a county, or by commodity such as having only dairy farmers in a meeting.

  The ideal format for group meetings is for 15 to 30 farmers to meet for 2 to 4 hours. This size and length is best suited for generating the two-way discussion needed for learning and understanding. Fewer than 15 farmers increases the cost per farmer, while meetings with more than 30 farmers make it difficult to stimulate the discussion needed for effective learning.

  One-on-one meetings with farmers should be designed to encourage discussion about how the results from evaluations match what the farmer thinks the results should be. Farmers, like all adults, need to time to explore new information that conflicts with or provides an alternative view of the most efficient practice or practices for their farm.

- Discussion, Not Lecture.—Unlike many farmer educational efforts, adaptive nutrient management is a two-way discussion in which the farmer plays a key part in the decision about what the information means and how to put it to the best use to improve management. As a result, an adaptive management leader is more of a facilitator than a lecturer.

  Through practice, a leader will learn if a question should be answered with a question or should be answered with information. Questions about technical details of a test or procedure, such as a question about how a plot trial was established or how a sample for the corn stalk nitrate test was collected, should be answered with information. Questions about how a farmer should change a management practice based on assessments of that practice completed on the farmer's fields should be answered with a question.

  For example, a farmer asks what rate of N should be applied to a field with 2 consecutive years of cornstalk nitrate concen- trations greater than four times the threshold for excessive N availability. The answer should be a conversation with the farmer structured by a series of questions. Typical questions to the farmer could be:

  - What rate of N do you think should be applied?
  - What rate did you apply in the past 2 years?
  - How confident are you in the results of the cornstalk test?

- How green was the corn a few weeks after tasseling?
- What is your perception of the amount of risk you would take if you reduced the amount of N applied by half?

The answers the farmer provides to the questions will guide the conversation. The conversation should end when the farmer has answered the question for him or herself . Following up with an endorsement of the farmer's decision will build confidence necessary to make decisions based on data from their farm, and foster a strong relationship between the group leader and the farmer.

- Being Prepared.—The leader should always have an available presentation with background information about assessments used to improve the practice being discussed. Include all the slides shown at the first year's meeting describing the assessments and example slides of typical assessment results. The slides should be used to guide discussions and can be used to demonstrate important concepts. Examples of useful slides for enhancing learning could be slides showing the variability of N needs inside fields from assessments completed using active sensors of the greenness of corn, or a summary of results of plot trials completed in a State showing the yield response to three rates of N lower than the rate typically applied by the farmers in the group.

Summary

Adaptive nutrient management using the on-farm field trials protocol enables growers to make well-informed and documented decisions on how to adjust their management to be more profitable and sustainable. The protocol helps the grower establish and test a hypothesis in consideration of the biological processes taking place in their fields. The process provides an analytical method for determining if a significant difference occurred between the existing and proposed treatments.

Adaptive nutrient management is dependent upon following well-accepted protocols for planning and then evaluating accurate results. By following a well-designed planning and evaluation procedure, true differences among tested treatments can be determined, and superior management options can be selected and applied.

Reference

Anderson, D. 1993. On-Farm Research Guidebook. Department of Agricultural Economics. University of Illinois Extension, Urbana, IL.