

Technological Advances in Nutrient Management

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Introduction

This module is the fourteenth in a series of Extension materials designed to provide Extension agents, Certified Crop Advisers (CCAs), consultants, and producers with pertinent information on nutrient management issues. To make the learning 'active,' and to provide credits to CCAs, a quiz accompanies this module. In addition, realizing that there are many other good information sources including previously developed Extension materials, books, web sites, and professionals in the field, we have provided a list of additional resources and contacts for those wanting more in-depth information. This module covers a portion of Rocky Mountain CCA Nutrient Management Competency Area VII: Nutrient management planning.

Objectives

After reading this module, the reader should:

1. Become familiar with recent advances in nutrient management.
2. Understand pros and cons of available technologies.
3. Recognize connections between different types of technology.



Background

Innovations during the last decade in computers, telecommunications, and satellites have increased the number of nutrient management tools. Driving these technological advances is the growing awareness of soil nutrient variability, the possibility of higher yields, improved quality, and stricter environmental regulations requiring reduced nutrient leaching, runoff, and loss as described in *Nutrient Management Module 12* (NM 12). Technologies include Geographic Information Systems (GIS), the Global Positioning System (GPS), Remote Sensing (RS), in-field sensors, yield monitoring and mapping, hand-held computers, and variable-rate technology (VRT). Often technologies are used simultaneously or in conjunction with one another, such as with Precision Agriculture (PA). As these technologies become less expensive and more user-friendly, they are more accessible and useful to producers. However, not all technologies are appropriate for every operation, and it is important to understand the

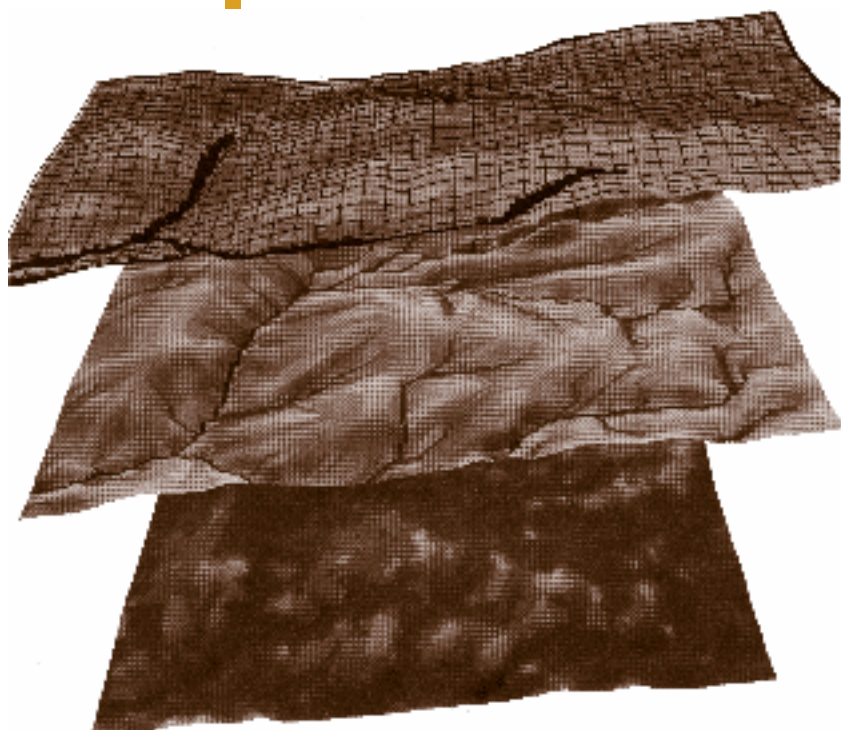


Figure 1. GIS layers of yield (top), topography (middle), and soil conductivity (bottom) (From Westervelt and Reetz, 2000).

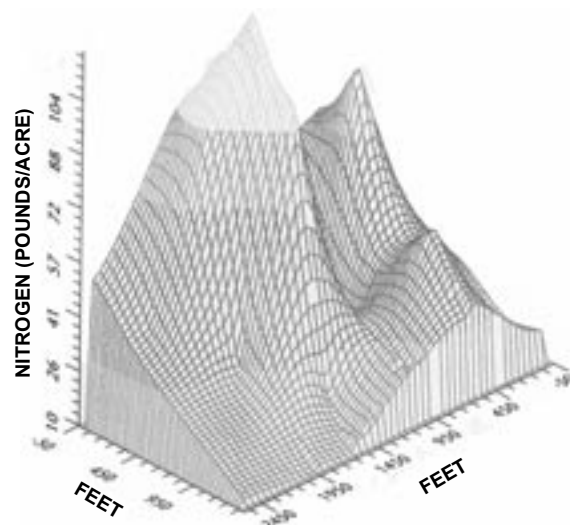


Figure 2. A three dimensional grid model shows N levels ranging from 10-120 lb/acre (From Richter, 1991).

advantages and limitations of each system. Additionally, systems may be mixed and matched to fit particular goals, budgets, and needs. The mention (or non-mention) of any products in this publication does not indicate endorsement or lack of endorsement of any particular product.

Geographic Information Systems (GIS)

GIS are computer software systems designed for entering, storing, manipulating, analyzing, and displaying spatial information (Morgan and Ess, 1997). Data entered into GIS include not only the 'attribute' (e.g., N application amount) of interest, but also the geographic location of the attribute on the earth's surface. GIS can display multiple attributes as individual layers or combine them into one image (Figure 1).

In addition to displaying multiple layers, GIS can store, calculate, and model current or historical data. For example, you can enter annual nitrogen (N) application rates, view changes over time, and estimate needs for the next growing season by calculating approximate nutrient changes in availability for the current crop. If you want a visual display of application rates, you can also use any number of GIS

models (Figure 2, at left). One particularly useful model for nutrient management is a Digital Elevation Model (DEM), which represents surface elevations similar to a topographic map. In addition to illustrating application rates, DEMs can be used to model water and nutrient content, accumulation, and movement across or out of fields.

The diverse capabilities of GIS make it appealing, but a few considerations are necessary before using it. There is generally a monetary investment (ArcView 3.3 GIS software for Windows is about \$1,100 in January 2004 dollars), and learning new technologies requires a time commitment. However, a number of inexpensive and user-friendly Internet courses and books are available (see Appendix, p. 11).

Global Positioning System (GPS)

GPS uses satellite signals to calculate latitude, longitude, and elevation. The U.S. Department of Defense (DoD) began developing the system in the early 1980s, and it was completed in 1995. GPS was originally created for military navigation, but the system of twenty-four satellites has always been available for the general public. Due to civilian pressure, in 2000

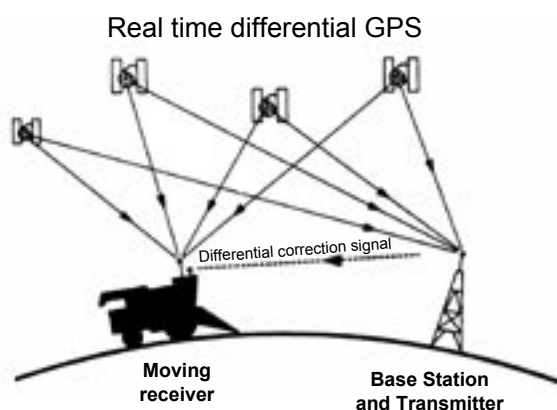


Figure 3. With real-time DGPS, both satellites and a stationary receiver transmit signals to the moving receiver, correcting for atmospheric or other interference (From Morgan and Ess, 1997).



Figure 4. GPS satellites can be simultaneously used for multiple applications. This image shows only one of four satellites needed for accurate locations (From Morgan and Ess, 1997).

the DoD also discontinued ‘Selective Availability,’ or the intentional scrambling of signals (Morgan and Ess, 1997). Errors such as Selective Availability and atmospheric interference led to the creation of ‘Differential Correction’ (Figure 3).

Producers almost exclusively use Differential GPS (DGPS) because it is more accurate (generally within about one yard) than GPS without correction (>10 yards). However, researchers and producers are beginning to find greater accuracy with uncorrected GPS. One study of both wheat and

Q&A #1

Why do I need four satellites for GPS to work?

GPS receivers use a principle called ‘trilateration.’ Trilateration determines the position of an object by measuring its distance from other objects with known locations. A GPS receiver determines its distance from a satellite by using the time it takes for a signal to travel from the satellite to the receiver. If you know your distance from one satellite, you could be anywhere on a sphere surrounding that satellite (the satellite is at the center of the sphere). If you add distance information from a second satellite, you narrow your location to the intersection of the two spheres around those satellites. Addition of a third sphere locates you at one of two points. A fourth satellite signal eliminates one of those two points, giving you a confident location. Many GPS receivers can read up to twelve satellites; as more satellites are shown on your receiver, the accuracy of your position increases (Adapted from www.montana.edu/places/gps).

Q&A #2

What is the electromagnetic spectrum?

Light travels in the form of waves, or electromagnetic energy. The electromagnetic spectrum is the continuum of different lengths of energy, ranging from gamma rays to radio waves. Visible wavelengths are relatively short waves, and lie near the gamma ray part of the spectrum. Color differences are reflected in length variation of visible rays (e.g. red light is longer than violet light). Longer than visible wavelengths are 'infrared rays', which are generally used in detecting differences in plants and soils (Adapted from www.muextension.missouri.edu).

soybean fields found a positioning difference between GPS and DGPS of about two yards (Shannon et al., 2002), yet during periods of increased atmospheric error, this difference would likely be greater. A second study found an 86% correlation between yield maps created with GPS and DGPS systems, suggesting that GPS without correction is becoming a viable option as technology improves (Molin and Gimenez, 2002).

The potential applications of GPS in nutrient management are extensive. A GPS unit can be attached to a vehicle and used for guidance, thereby

eliminating overlaps and skips of nutrients or other inputs. This is particularly beneficial when using large equipment. GPS also enables sampling of soil and crops in the exact same location over time, facilitating management of a particular area that has excessive or limited nutrients. Lastly, GPS is essential in applying other technologies (discussed later) and is often used simultaneously on several pieces of equipment (Figure 4, previous page).

One drawback with GPS is satellite coverage; if the GPS receiver doesn't pick up at least four satellites (Q&A #1, previous page), then accuracy is compromised or a signal won't be recognized. Signal loss often occurs with vegetation interference, in narrow canyons, and in the presence of excessive electromagnetic radiation (e.g., a microwave transmitting station). Data gaps result when signals are lost, which lowers data quality.

Remote Sensing (RS)

RS involves gathering information for an area from remote 'platforms' such as satellites or airplanes. The RS satellite system uses reflected energy to record images (Figure 5). 'Electromagnetic energy' signals (Q&A #2; Figure 6) are recorded into a stream of numbers, which can be sent to Earth via satellite dishes and reconstructed to form digital or electronic images (Morgan and Ess, 1997). Airplane platforms may also use the electromagnetic spectrum or may record images with devices similar to regular cameras. Regardless of how the images are recorded, they also need to be processed, analyzed, and confirmed via 'ground truthing.' Ground truthing is verification of data accuracy by field investigation, such as confirmation of low production areas seen in RS imagery.

There are a number of RS applications for researchers and producers. For example, 'vegetation indices' (Q&A #3) compare two or more electromagnetic wavelengths to assess such variables as plant leaf area, organic matter, plant stress, and canopy biomass (Morgan and Ess,

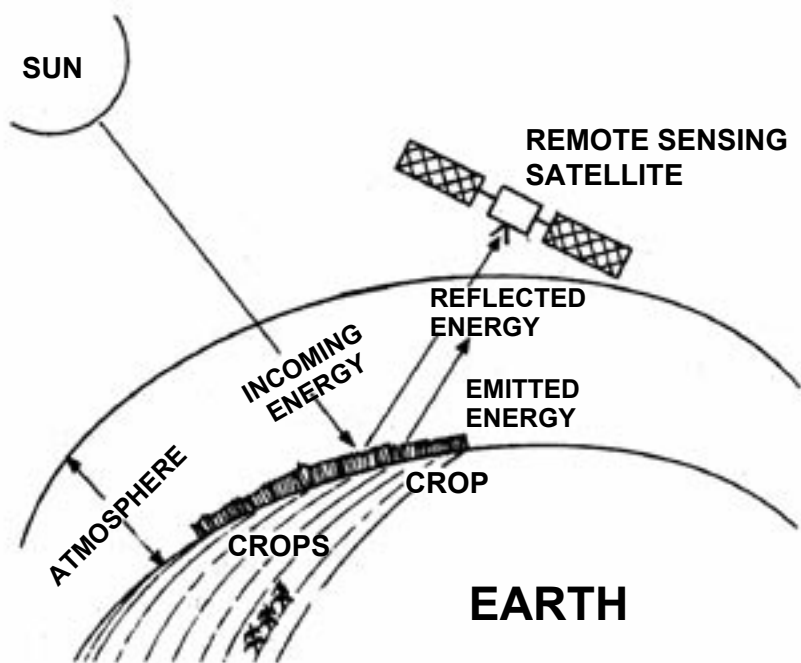


Figure 5. The Earth reflects a portion of the incoming solar radiation, which is then recorded by a RS satellite (From Morgan and Ess, 1997).

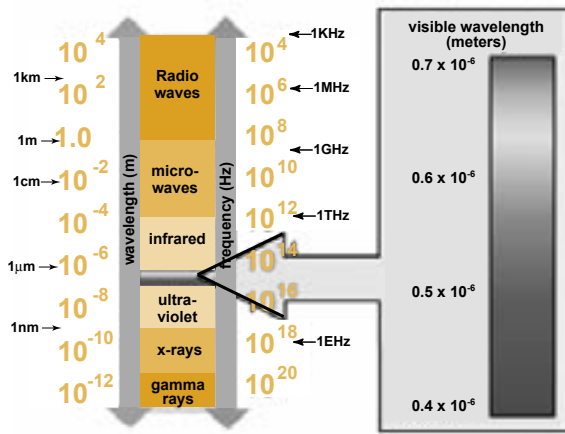


Figure 6. RS measures reflectance of the electromagnetic spectrum both inside and outside the visible range, and sometimes uses multiple bands for comparison (From <http://muextension.missouri.edu/>).

1997; Lubus et al., 2002). One example is 'NDVI' (Normalized Difference Vegetation Index), which is a ratio of infrared and red waves used to determine biomass. A Montana grazing study found live forage biomass and NDVI values to be well correlated, but NDVI was not as good a predictor of % N in biomass (Figure 7). Vegetation indices can also be assessed repeatedly over a season to identify crop

performance and yields. A nine-year study of wheat and barley in Montana found vegetation indices useful in estimating regional or farm-scale yield at the end of the growing season, but less effective in identifying early-season yield estimates (Lubus et al., 2002). An additional Montana study successfully identified no-till fields with RS imagery with 95% accuracy (Figure 8, next page).

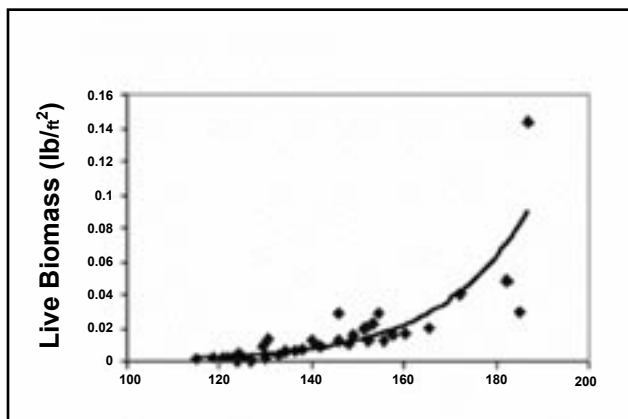
The application of RS to nutrient management has been slow due to expense, long data delivery time, inadequate repeat coverage, varying spatial resolution, and uncertainty of what nutrient is limited or in excess (National Research Council, 1997). Professional image processing is an essential step in using RS; this may take up to several weeks and can be costly. Cloud interference also results in data gaps, which is problematic with highly variable soil and plant

Q&A #3

How do vegetation indices work?

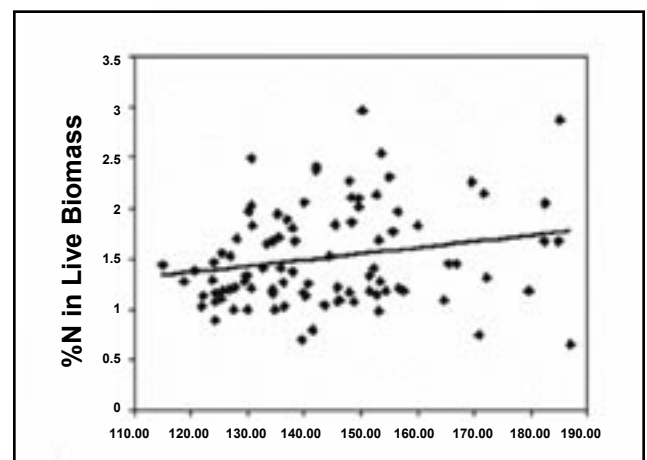
Green leaves contain the photosynthetic pigment chlorophyll *a*, which is strongly absorbed by red light (in the visible part of the electromagnetic spectrum). Conversely, near-infrared light either passes through or is reflected by live leaves. Therefore, areas of little or no plant cover will appear similar in both wavelengths, while areas dense with green vegetation will be reflected brightly with near-infrared waves and will appear dark with red waves. These differences in shades and colors are used to potentially indicate different crops and/or nutrient levels (Adapted from <http://www.uswcl.ars.ag.gov/epd/remsen/vi/VIWorks.htm>).

a



MSR-16 NDVI

b



MSR-16 NDVI

Figure 7. NDVI values correspond to live biomass, but are unable to indicate % N in live biomass in one Montana study (From Thoma, 1998).

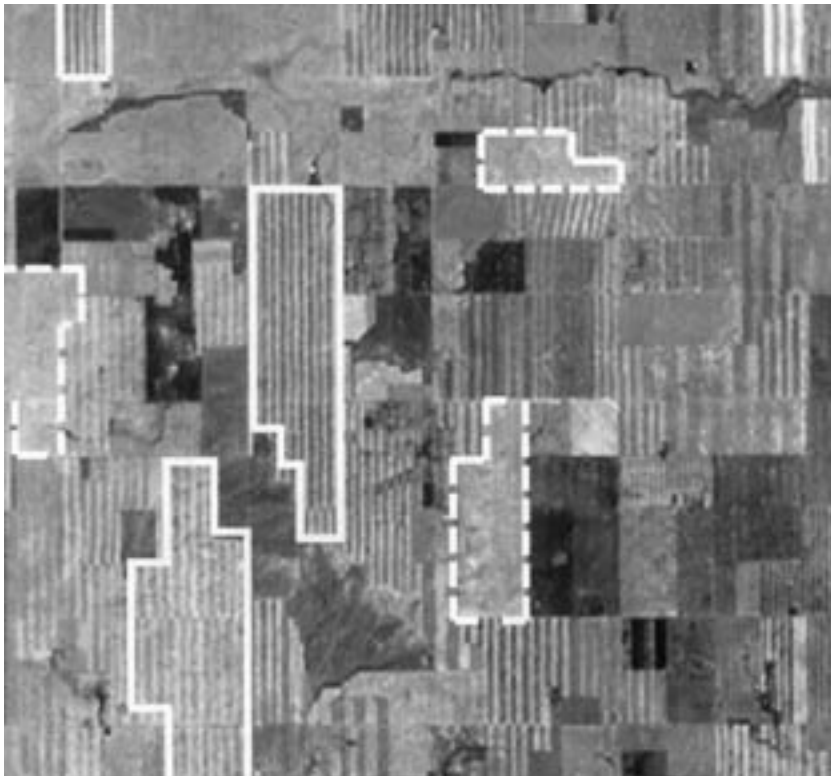


Figure 8. A RS image showing selected till (bold white) and no-till (dashed) fields (From Bricklemeyer et al., 2002).

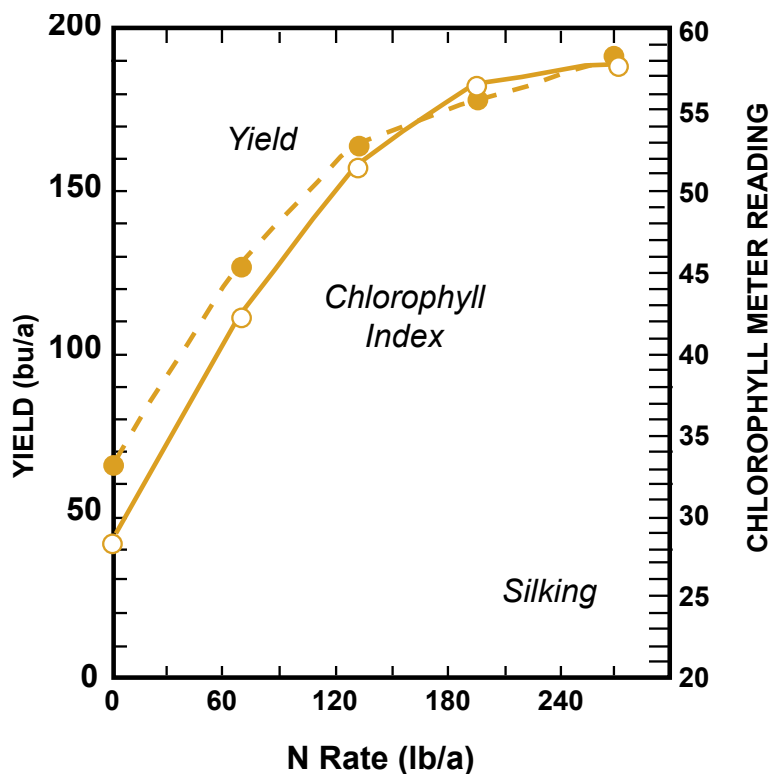


Figure 9. Effect of N rate on chlorophyll meter reading and yield for irrigated corn (From Havlin et al., 1999).

properties. Additionally, because a number of different conditions cause crops to change color (*NM 2* and *NM 9*), caution is needed when using RS to detect nutrient deficiencies.

In-Field Sensors, Monitoring, and Mapping

METERS AND SENSORS

Chlorophyll meters may be used to assess crop N status. Since leaf chlorophyll content is related to N nutrition (as well as other nutrients), measuring chlorophyll can give an indication of N present in a crop and potential yield (Figure 9). Once a correlation has been established between a chlorophyll meter reading and yield, N could be topdressed if chlorophyll is inadequate. A problem with chlorophyll meters is that pinpointing specific deficiencies is difficult. Changes in chlorophyll can be caused by a number of conditions (*NM 2* and *NM 9*), so these meters are best used only as potential indicators of deficiencies. Plant tissue should be tested to confirm N amounts or compared with an area that is known to be adequately fertilized (Q&A #4, at right).

'Electrical conductivity' (EC), or the capacity of soil to conduct electrical current, is highly influenced by soil texture (Lund et al., 2001). Soil texture is in turn correlated to N activity and movement in soil, so researchers and producers are increasingly exploring the use of EC meters to infer N needs and application rates. One study used EC meters in addition to topography, yield maps, and RS to identify low N sites and then apply N site-specifically (Lund et al., 2001). When compared to traditional single application rates, the new technology increased grain yield by 11% and protein by 0.8%. This illustrates that although EC meters do not directly measure N, they are useful when used in conjunction with a suite of other technologies.

Sensors that measure soil moisture

can also be used to estimate soil texture, which is related to soil productivity, nutrient transport, and potentially salt impact on soils. There are many types of soil moisture sensors available (<http://sis.prosser.wsu.edu>). Again, determining whether a sensor or meter is appropriate and cost-effective for your operation is critical before purchasing.

YIELD MONITORING AND MAPPING

Yield monitors can attach to combines or conveyors to measure grain yield and grain moisture from specific areas in the field. Yield maps visually display data gathered from monitors (Morgan and Ess, 1997). Yield monitoring and mapping identify in-field variations in yield, facilitating the subsequent year's site-specific application of nutrients. Yield monitor use is widespread (Figure 10), partly because exploring yield data can reveal relationships in nutrients, soil types, or other factors that affect production (Morgan and Ess, 1997). Yield monitor accuracy is continuing to improve as well. An Iowa study compared yield monitor measurements to an electronic scale, and found yield measurement differences to range from 2% to 14% (Arslan and Colvin, 2002). Yield monitor accuracy improved with calibration, constant combine speed, and longer test plots.

HAND-HELD COMPUTERS

Mobile computers are the newest nutrient management technology. Handheld computers store and display database information, maps, and GPS positions. Advantages of these systems are that you can view existing data in the field, access the Internet via wireless technology, measure distance, area, and bearings, directly input and download field data into a larger computer, and view satellite imagery and GIS information while in the field. For example, in-field soil nutrient tests or chlorophyll meter measurements could be input, compared to previously established fertilizer recommendations, and application could occur on the same

day. An additional option with hand-held computers is using a small, portable printer that can automatically print data layers or other desired information.

VARIABLE-RATE TECHNOLOGY (VRT)

Variable-Rate Technology (VRT) allows producers to spatially vary application rates of inputs such as nutrients, fertilizers, and seed. Historically, intensive soil sampling has been necessary to determine application rates (Long et al., 2003). However, this can be expensive when compared to general crop values in Montana and Wyoming. Researchers and producers are instead exploring VRT applications and ways of making the technology less expensive.

Q&A #4

How do I increase the probability that my chlorophyll meter is reflecting N levels instead of other nutrients?

Since chlorophyll indicates other properties in addition to N levels, it is important to isolate what specifically is causing differences in color. To minimize the effects of properties other than N, you can establish a small reference area that has been adequately fertilized with N. Then you can compare meter readings between this area and other areas where you don't know if N is sufficient (Adapted from <http://www.ianr.unl.edu/>).

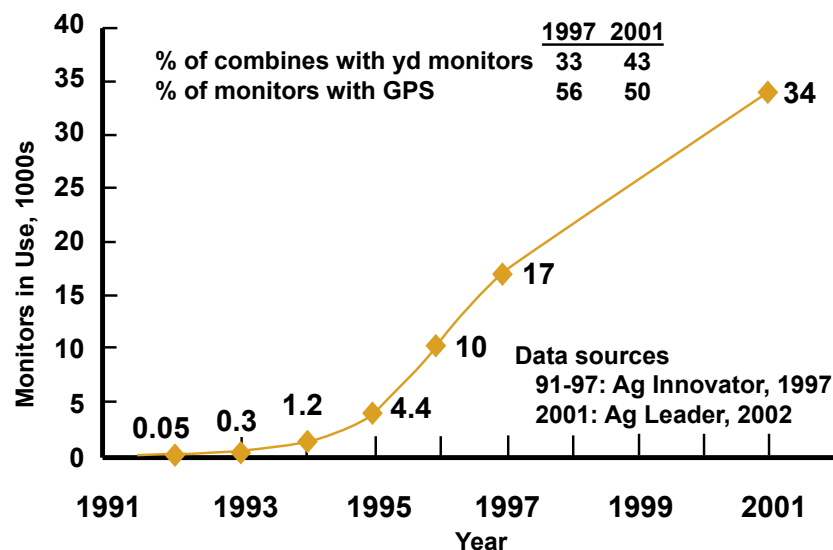


Figure 10. Growth of yield monitors in the United States shows increasing interest in technologies (From Fixen, 2002).

There are two types of VRT systems: map-based and sensor-based. Map-based VRT systems assess application needs by using a map created from yield goals, field history, and field characteristics. A GPS unit and a database of desired application rates are attached to a vehicle, and these systems “read” a map to determine vehicle position and where nutrients should be applied. Sensor-based VRT systems also attach to vehicles, but differ from map-based systems in that they test nutrient variability and apply nutrients without previously gathered data (Morgan and Ess, 1997).

There are benefits and limitations to both types of VRT. A potential benefit of map-based systems is determining application rates prior to going into the field. This helps ensure that there will be enough product, and if there are any concerns about the recommended rates, they can be addressed before application (National Research Council, 1997). Although time between gathering data and application can be a benefit, it can also be problematic because soil conditions (such as nitrate and soil moisture content) change, and may be significantly different by the time application occurs. Map-based systems also use a limited number of samples and extrapolate data to entire fields or areas of fields, such as specific soil types. This can potentially result in a misrepresentation of variable field conditions. In order to store necessary data, a GPS and usually GIS software is required to use a map-based system. In contrast, sensor-based systems don’t require GPS or GIS, and since they measure need and apply product simultaneously, they are more likely to incorporate the correct nutrient or product amount than a map-based system. However, sensor-based systems are unable to store field maps or historical data, which is a limitation if you want to use additional data for application. Sensor-based systems also need to be calibrated or correlated

with crop response, whereas map-based systems can use current calibration curves.

Research concerning the effectiveness of VRT has been ongoing at the Northern Agricultural Research Center in Havre for the past decade. A study comparing site-specific versus uniform N application shows promise of improved uniformity of grain quality with site-specific application (Dan Long, personal communication). Research has shown that profitability of site-specific application depends on soil moisture, market conditions, treatment costs, the economic status of the farm, and the extent of N field needs. Continuing development of grain protein sensing technologies will hopefully make site-specific N application more profitable.

Precision Agriculture

Precision Agriculture (PA) is the management of field variability to improve economic returns and reduce environmental impact (National Research Council, 1997). It has always been known that in-field variation of yield potential and quality, nutrients, water, and soils exists, but the technology to identify and manage variability precisely was not readily available until the early 1990s (Westervelt and Reetz, 2000). VRT and yield monitoring/mapping are specific applications of PA; however, all of the previously discussed technologies can be used in PA, either independently or in conjunction with one another (Westervelt and Reetz, 2000; Morgan and Ess, 1997). With the larger agricultural operations that exist today, in-field variation of nutrients and yields is larger; therefore, nationwide exploration of PA is becoming more common (Fixen, 2002).

Research projects in the Northern Great Plains are illustrating the usefulness of PA adoption in this region. A Montana study of hard red spring (HRS) wheat showed that more precise N applications can significantly enhance crop quality (Long et al., 2002). However, the

researchers further showed that PA will not be economically viable to most producers in the Northern Great Plains until there are more monetary incentives for growing above-average quality crops.

Resources in Montana and Wyoming

The Internet provides a number of links to information, courses, and contacts concerning nutrient management technologies. Links to the following resources are listed in the Appendix. The Earth Observing System (EOS) offers links to GIS workshops and online courses. Another resource is the Precision Agriculture Research Association (PARA), a group of Montana researchers and producers that explore PA applications from both a research and an applied perspective. This site offers a comprehensive overview of GPS and GIS as well as links to a number of other helpful sites. In Wyoming, the Geographic Information Science Center (WyGISC) has short GPS training courses and a website with links to a number of resources and information.

Considerations When Choosing Technology

The complexity of recent technologies makes choosing those most appropriate for a specific operation difficult. There are a number of considerations, including compatibility of software and hardware, the need for the technology, the time you're interested in committing, and cost. Software and hardware compatibility, as well as need, are easily sorted out through educating yourself prior to purchase (the Internet is a great source) and asking questions when deciding what to purchase.

Cost is perhaps the most important consideration when deciding whether or not to use new technologies. Many of the advancements in nutrient management are affordable and accessible; certainly the

Internet is one source of easily accessed, low-cost information. One example of this is the option of downloading the GIS software ArcExplorer from the Internet (<http://www.esri.com/software/arcexplorer>). This program is more limited than ArcView in its capabilities, but is a good place to start with GIS.

Some technologies still remain outside of most budgets, especially for smaller operations. To help minimize costs, one possibility is to combine efforts with neighboring farmers. For example, RS of several farms will be less expensive than if each farm independently pays for imagery. Another way to afford technologies is to work with companies and consultants to tailor systems that are most helpful and affordable for an operation. Lastly, it is important to remember that the costs of most technologies vary greatly. For instance, recreational grade GPS receivers start at about \$100 and DGPS units with sub-yard accuracy range from \$2,500-\$5,000, depending on features. Again, becoming educated about technologies and prices before buying is critical.

Summary

Technological advances in the past decade have created new opportunities for input management on farms. The possibility of using images taken from space to manage field variability is just one of the recent changes in agriculture. Inexpensive and useful technologies such as GPS can help with numerous aspects of nutrient management. As technologies continue to improve, they will become more user-friendly and inexpensive. Developments in technology are occurring every day, and the possibilities for the future are numerous. For now, the bottom line is to make an educated decision about whether the benefits in management improvement outweigh the time and monetary costs of implementing new technologies.

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APPENDIX

Books

Getting Started with GIS. K.C. Clarke. 2002. Pearson Education, New York, NY. 352 pp. Approximately \$76.

GIS in Site-Specific Agriculture. J.D. Westervelt and H.F. Reetz, Jr. 2000. Interstate Publishers, Inc., Danville, IL. 58 pp. Approximately \$16.

The Precision-Farming Guide for Agriculturalists. M. Morgan and D. Ess. 1997. John Deere Publishing, Moline, IL. 117 pp. Approximately \$26.

EXTENSION MATERIALS

Nutrient Management Modules (1-15) are available and can be obtained online or at the address below (add \$1 for shipping).

MSU Extension Publications
P.O. Box 172040
Bozeman, MT 59717-2040

All are on-line in PDF format at <http://www.montana.edu/wwwpb/pubs/mt4449.html>

See **Web Resources** below for online ordering information.

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WEB RESOURCES

<http://www.eoscenter.com/>

EOS website focused on GIS that offers regional links, services, and contacts.

<http://www.montana.edu/places/>

PLACES website that provides excellent GIS/GPS information, links to other helpful websites, information for a GPS workshop, a land and climate map of Montana (MAPS), and PARA information and links.

<http://www.wygisc.uwyo.edu/>

WyGISC website that has great links to resource projects, digital photos, and contacts in Wyoming.

<http://www.wy.nrcs.usda.gov/wygis/gis2.html> and

<http://nris.state.mt.us/gis/default/htm/>
<http://www.epa.gov>

Wyoming and Montana websites that list state contacts and regional information.

<http://www.montana.edu/publications>

Montana State University Publications ordering information for Extension Service Publications.

<http://landresources.montana.edu/FertilizerFacts/>

Fertilizer Facts summarizing fertilizer findings and recommendations based on field research conducted in Montana by Montana State University personnel.

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