United States
Department of
Agriculture

Natural
Resources
Conservation
Service

Agronomy Technical Note No. 3

February 2010

Precision Nutrient Management Planning

Issued February 2010

Acknowledgments

Soil Quality—Agronomy Technical Note No. 21 was prepared by **Richard Fasching**, conservation agronomist, West National Technical Support Center (WNTSC), Portland, Oregon; **Patricia Turman**, State agronomist, Murfreesboro, Tennessee; and A**ziz Rahman**, State nutrient management specialist, Fresno, California.

Figures contained in this technical note are actual results of real-time digital imagery used with permission and provided by **Russ Linhart**, GreenSeeker product specialist, Trimble Navigation Ltd., using one form of precision agriculture technology.

For further information, contact the WNTSC at (503) 273-2400.

This page intentionally left blank.

Precision Nutrient Management Planning

Introduction

Precision agriculture is a rapidly growing and developing area in the agricultural industry. Agricultural producers are looking closely at precision agriculture technology for the benefits it provides in relation to time management, efficiency, economics, and natural resources conservation.

Increases in the use of precision nutrient management require accurate and productive precision nutrient management planning. A precision nutrient management plan is a dynamic tool and, once developed, should be monitored and adjusted on a regular basis.

Basic components of a precision nutrient management plan

A precision nutrient management plan must meet all the requirements of the Field Office Technical Guide, Conservation Practice Standard (CPS) Code 590, Nutrient Management, which addresses all the components to be included in a plan. There are certain components that must be addressed in more detail when dealing with a precision nutrient management design. These components include aerial imagery or site map(s) and a soil survey map of the site; results of soil, water, manure, and/or organic by-product sample analysis; results of plant tissue analyses, when used for nutrient management; a complete nutrient budget design for nitrogen (N), phosphorus (P), and potassium (K) for the crop rotation or sequence; adaptive nutrient management application rates, timing, form and method of application and incorporation, and guidance for implementation, operation, maintenance, and recordkeeping.

This technical note will review the aspects of the components and the additional detail recommended based upon the type of technology used in implementing a precision nutrient management plan. The information covered in this technical note is a vital part in developing an accurate and effective precision nutrient management plan.

For the precision nutrient management plan to be an effective tool, the following, as a minimum, must be completed:

- Design a nutrient budget that considers all sources of nutrients available for crop production such as animal manures, organic by-products, mineralization, waste water, irrigation water, and legumes.
- Identify within field variability and delineate corresponding management zones.
- Determine realistic yield goals for each management unit and zone.
- Compare performance of nutrient rates, timing, placement, and alternatives to nutrient application (cover crops).
- Determine causes of yield losses due to natural, human induced, or equipment factors.
- Identify nutrient sufficiency, deficiency, and toxicity areas.
- Determine any other productivity problems and soil amendment options.

Aerial imagery, site map(s), and the soil survey
Aerial imagery or site maps and the soil survey map are the first key items used when developing a precision nutrient management plan. These tools, including knowledge of previous land use(s), help determine management zones, and soil sampling areas. Even with all this information, imagery does not always show, or even help explain within field variations that may be induced by management decisions, climatic conditions, geologic characteristics, and/or other sources of variation. Realize that not all imagery or maps are created equal. The latest, highest resolution maps should be used whenever possible. A field visit and producer involvement is invaluable when interpreting imagery.

The following information may be used to develop a precision nutrient management plan based on the type of technology used.

Nutrient management zones—Management zones are determined based on interpretation of measurable differences in nutrient status within the management unit in addition to other layers used, that is, yield data from previous years, digitized scouting reports, and soil survey layers. The number of zones is dependent on variables within the field and should be designed in accordance with the capabilities of the application equipment and needs of the producer. Each established management zone may have one application rate prescription. Because precision agriculture technology is rapidly changing, variable rate equipment technology can effectively apply numerous (up to 250 or more) rates based on variation. Where this type of equipment is used, a range of rates may be designed across a particular zone (rather than only one specific rate per zone).

Initial delineations of nutrient management zones can be determined using any one or a combination of the following methods:

- **Multi-spectral satellite imagery or aerial ortho-photography** can accurately portray field conditions for the yield goal defined. There are significant differences in data quality of imagery from year to year, and the vintage (date) and photography source used is needed for plan documentation. Imagery with dates corresponding to seasons of drought or extreme moisture should be avoided, as it is difficult to correlate with actual within-field variability. Using image analysis software or photo interpretation, imagery can be evaluated for information representing variations in soil color, soil moisture, crop vigor, crop production (vegetative indexing), pest infestations, nutrient deficiency or sufficiency, and toxicity. This information is used to delineate initial management zones for variable rate nutrient applications, and the delineations are transferred to the nutrient application software.

  This process uses digital soil survey data as a layer, and if possible, digital yield data from previous years. Soil sampling may be completed prior to establishment of the zones or after zone establishment. If sampling is completed post zone establishment, it may be necessary to adjust zones dependant on sample analysis.

- **Grid soil sampling** involves dividing a field into equal square or rectangular sections (grids) of several acres in size. The analysis from each grid sample is then used to establish zones based on one or several of the analysis results.

- **Electro-conductivity (EC) monitoring** determines measurable differences in soil texture, structure, organic matter, drainage, topsoil depth, soil water contents, and other soil characteristics. After collecting EC data, management zones are then determined based on an interpretation of differences in soil properties within the management unit along with layers of other applicable digital data, that is, digitized yield data, scouting reports, and soil survey layers. Soil sampling is required to correlate EC readings prior to setting the zones and application rates.

- **Land-based optical sensing** is a form of using vegetative indices to optically scan the growing crop in real time and responding to variability. Where this type of precision agriculture is practiced, soil sampling may not be necessary to establish zones; however, it is still recommended that at least a bulk sample be analyzed. Where required, calibrate according to manufacturer's recommendations. Soil sampling within primary management zones should be completed after harvest to validate nutrient applications and prepare for the following year's crop(s).

Soil survey data—Digitized soil survey mapping and associated data are essential layers that should always be used with precision agriculture nutrient management design. Soil survey information provides valuable information including such characteristics as soil texture, horizon depth, hydraulic conductivity, physical and chemical properties, erosivity, and numerous other factors that might affect site potential. Soil Survey Geographic database (SSURGO) is digitized soil mapping available for most counties at http://soildatamart.nrcs.usda.gov/, where shape files and attributes are the desired format, or at http://websoilsurvey.nrcs.usda.gov/app/ for non-GIS users. Maps and data are also available through Customer Service Toolkit. All three sources provide the same vintage data. Additionally, using the expertise of a professional soil scientist to establish management zones and assist in collecting soil samples is recommended.

Results of soil, water, manure and/or organic by-product sample analysis and results of plant tissue analyses, when used for nutrient management

The information provided to meet this component will depend on the soil sampling method. The method used is dependant on the type of precision management system the producer will use. As mentioned earlier, the producer can choose from different methods from a grid management system to a zone management system.

Soil sampling and testing is a required step in developing an accurate precision nutrient management plan. Depending upon the precision technology used, soil sampling is (usually) completed first. Each soil sampling location is digitized using Global Positioning System (GPS) locations to collect the points where soil tests are conducted. The analysis of these samples can then be used as another layer along with imagery and SSURGO and other layers to determine management zones. In general, numerous subsamples are collected to provide the most accurate nutrient concentration depiction. Other methods of precision nutrient management will require the identification of zones first, then subsequent zone soil sampling. This process may require adjustment of zone boundaries after analysis results are considered. In some parts of the United States, a soil test analysis may not be a reliable tool to determine a nitrate application prescription due to inherent variability caused by temperature fluctuations and large amounts of precipitation, making a nitrate test vary dramatically from one week to another.

Methods often used for soil sampling include:

- **Grid soil sampling** involves dividing a field into equal square or rectangular sections (grids) of several acres in size. As a minimum, sample analysis must include P, K, organic matter (OM), pH, and nitrate (NO_3)when applying variable-rate N. Management zones are then determined based upon an interpretation of measurable differences in nutrient status within the management unit in addition to other layers used (previous years yield data, digitized scouting reports, soil and survey layers). For precision nutrient management technologies where real-time optical sensors are used, soil sampling by grid or zone methods are not necessary to determine nitrate application rates. However, calibration should be completed prior to using real-time sensor methods.
- **Zone soil sampling** involves the collection of soil tests for each zone established. If grid soil sampling was completed, this step can be skipped. Otherwise, zone soil sampling must be completed as indicated in soil sampling and testing. The number of soil samples and sub-samples required is based on Land Grant University guidelines for soil testing and must be "representative" of the zone.

Where precision agricultural methodologies use soil tests to determine nutrient management zones, current soil tests must be used to effectively plan for nutrient applications. Due to potential annual variability, N that is applied using variable rate technology should be tested each year an annually planted crop is produced. P and K may be completed once every 3 years after a baseline, or consistent database, is established. Remember that all soil sampling procedures, analyses, and recommendations must meet the requirements of the CPS Code 590.

Documentation of the soil sampling method used is part of the precision nutrient management plan. Plan documentation for each GPS-recorded soil test location (point data) will include an electronic file or map of the soil sampling locations, date of current soil tests, and soil laboratory used; an electronic file or map with soil test results of all nutrients tested; and an electronic file or map of the soil test recommendations for all nutrients being variably applied. After plan development, regular soil testing of soil nutrient availability may be required to maintain plan accuracy, especially when dealing with variable rate N applications.

Where manure and/or organic by-products are being applied to a field in conjunction with variable rate application of commercial fertilizer, the amount of each nutrient added from the manure is accounted for in the nutrient budgeting process.

Plant tissue analysis coupled with satellite imagery may also be used to identify a management zone. The location of the tissue test is recorded using GPS. The vintage (date) and photography source used, along with GPS locations of the tissue test, provides another layer that determines soil sampling locations within a field. This method typically has the soil samples collected a year (or more) after the imagery date and tissue testing. The soil test results are then used to further refine management zones and the precision nutrient management plan.

Realistic yield goals

To ensure proper quantities of nutrients are applied, appropriate yield goals must be set. This process is slightly different depending upon the type of precision agricultural system being used (grid versus zone). In simplest terms, a separate yield goal is established for each grid (for each 5-acre grid sample area) depending on the soil analysis results in that particular grid. Depending upon the ability of the variable rate application equipment and on the analysis results, numerous yield goals could be established (a different one for each grid). Or, a limited number of yields could be established for a range of analysis results (a maximum of five separate yield goals, one of which must be assigned to each grid area).

In a zone management scenario, it is common to establish one realistic yield goal for the entire zone. Across an entire field, there may be as few as 2 or 3 yield goals or up to as many as 10 to 15, again, all dependent on application equipment capabilities. In all cases, it is essential to set yields to realistically achievable levels to minimize potential for nonpoint source pollution.

Yield relationships will not always track similarly from crop to crop. That is to say, a management zone or grid considered to have the highest yield potential for one crop may not be the highest yielding zone for a different crop.

Nutrient budget

A nutrient budget designed for precision nutrient management includes each nutrient being variably applied. The budget considers all nutrient sources to be applied such as animal manures, organic by-products, waste water, and irrigation water. The budget then becomes the nutrient application prescription (recommendation) used by the applicator to apply the nutrients. Budget documentation includes application prescription maps (sometimes called recommendation maps) for each nutrient variably applied detailing the target rates to be applied. If other data were used in creating the application prescription map, a description of that information must be provided, as well.

The nutrient budget is a complete budget of N, P, and K. If any one of these nutrients is applied without the use of variable-rate application equipment, a budget for that nutrient is still required. For example, if P and K are being variably applied and N is not being applied at a variable rate, a N budget is still required to meet CPS Code 590.

Implementation, operation, maintenance, and recordkeeping

After the plan is designed, nutrients are applied using GPS-guided application equipment capable of interpreting digital management zone information. The nutrient application prescription is provided to the producer and the nutrient applicator who then applies nutrients according to the prescription. A minimum of three application rates is typically implemented; high, medium, and low nutrient quantities based on realistic yield goals and cost. A digitized application record is recorded by the applicator as nutrients are applied. This digitized data layer is part of the plan documentation for nutrient application and can also be used to analyze potential variation for following year prescriptions._

To ensure that potential leaching, runoff, or volatilization is minimized, timing of nutrient application must correspond as closely as possible with plant nutrient uptake. N application in the fall is typically not recommended except for fall seeded crops.

Application records that provide information on all nutrient sources applied should be maintained. This includes the right time, right place, right amount, and right source. All nutrients that are variable rate applied will have electronic or "as-applied" maps for this purpose. When manure or organic by-products are applied, additional information is needed such as weather conditions at time of application. The recordkeeping information for all nutrient sources applied will need to meet the CPS Code 590.

Yield data are some of the most important data elements that can be used to design a nutrient management plan. Yield data should be collected on a field basis or on a management zone basis. When a GPS-guided yield monitor is used (strongly recommended), the yield data are even more precise. A GPS-guided yield monitor tracks and collects data that detail field variations. Yield data are collected at each harvest and incorporated as another data layer in the precision management plan for use in following year nutrient prescriptions. The yield data can assist in determining the location of problem areas in a field, which can be further studied. Determining the factor(s) causing the problem areas can result in a positive impact on crop yields where corrective management practices can be incorporated. When a GPS-guided yield monitor is used, the following information becomes part of the planning process:

- **Yield map development**—Data collected from the yield monitor are downloaded and imported into an appropriate software package. Post processing of the yield data is completed by range, equal count, or customized yield ranges. The counts or ranges of yield data are then used to develop yield maps with color-coded displays of the classes, ranges, or counts of yield values within the fields. The development of accurate yield maps from the yield data requires an appropriate data interpolation method to be used. A digital copy of yield data files and maps with summarized yield data should be included as part of annual documentation.
- **Yield map interpretation**—Yield variability can be identified by using topographic features, natural fertility, equipment-induced, management-induced, pest-induced, and/or other factors. The nutrient levels corresponding with GPS points from the soil tests can be displayed on yield maps to aid with interpretation. If available, additional GPS point data for other factors can also be used to aid in the interpretation of yield maps. Other field variation characteristics can be collected, digitized, and interpreted in the refined development of management zones. Characteristics such as insect, disease, or weed infestations

can be used as additional layers when assessing precision nutrient application rates. Annual yield variation can be used as additional layers when developing and modifying management zones

Maybe the most important aspect to precision agricultural technology is evaluation and assessment of results after implementing each year. As with all nutrient management plans, they are dynamic and must be refined each subsequent year. Gather additional data, collect updated map layers, review results and, by all means, make onsight field visits, where necessary, to determine what caused variations. Then, refine management zones (combine, split) for the next crop. Figure 1 is an example of precision nutrient management maps generated throughout the design and application process.

The map in figure 1 is the result of using real-time sensors on a young corn crop where all of the P and K and about half of the NO_3 were applied pre-plant. The map uses normalized differenced vegetative index (NDVI) showing a relative measure of the capability of the plants to grow on that particular day under existing conditions. The higher values indicate the plant is nearing its highest growth potential and would not respond as well to additional units of N. Notice on the black and white map, the drained areas and wetter areas (dark gray areas). The five shaded colors are the "zones" of variation.

Developed from the NDVI digital data shown in figure 1, figure 2 shows the design application prescription rates for additional top-dressed N (units of N). The surrounding fields that were not part of this precision agricultural nutrient management trial each received 60 units of side-dressed N.

Using the NDVI precision application methodology (fig. 3), an average of 24 units of N was applied across the field. The producer reported similar yield results between this field and the surrounding fields. However, the grower saved 36 units of N on the precision-applied N field. With 28 percent urea-ammonium nitrate (UAN) costing $.74 per unit, the producer realized a $26.64 per acre savings. Although the savings are measured in economics, they are also environmentally beneficial.

One point of interest: notice that the prescription level (Rx map) is slightly different than the actual application rate (map). The "off target lag" occurred with this system due to the physics of the variable rate application equipment's liquid plumbing system. This (and most) self-propelled sprayers regulate the speed of the solution pump to control application rate. The computer (in this case, can alter the rate about 100 times per second) outputs an application rate command to the spray rate controller. The rate controller sends out a command to the solution pump. The solution pump adjusts the flow to meet the rate command. The flow must then pass through distribution plumbing and subsequent restrictions on its way to the point of release at the nozzle. By the time all of this takes place, the pump has received a new rate command and has cut back flow. The applicator equipment could not keep up with the variation. If the applicator would have slowed down and applied at ground speeds that allowed the plumbing system to keep up with the variability in the fields, Rx and actual application rates would have shown greater similarity.

This digital yield map (fig. 4) shows some interesting results. For example, the dark blue area identified by the red arrow, actually recorded some of the lowest yields. Yet, in figure 2, the Rx, and in figure 3, actual application rates, higher amounts of N were prescribed and applied. Based on the NDVI readings, one would assume that this area would yield one of the highest in the field. So, why the poor results? Looking closely at the maps, this area is a low-lying area. The field received more than 24 inches of precipitation, considerably above its average. The low spots in the field became saturated causing stand reduction and denitrification and, thus, yield loss.

This digital elevation map of the field (fig. 5) identifies the low-lying areas in reference to the yield map. A trip to the field along with onsite data collection validated the cause of the yield losses in the low-lying wet areas.

Summary

Adoption of precision agricultural techniques is on the rise across the country as producers continue to manage scarce resources to ensure a sustainable livelihood of producing food and fiber. Precision application will continue to grow along with development of more effective equipment and better technologies. Gone is the day when a higher yield means greater income. Gone is the era when management was completed by "whole farm" or "whole field." Today, management occurs on an acre-by-acre or sub-acre basis, and greatest net profits are sought, rather than highest yields. Precision agriculture is one tool that allows producers to remain sustainable while protecting ecologically sensitive resources.

Figure 1 NDVI index

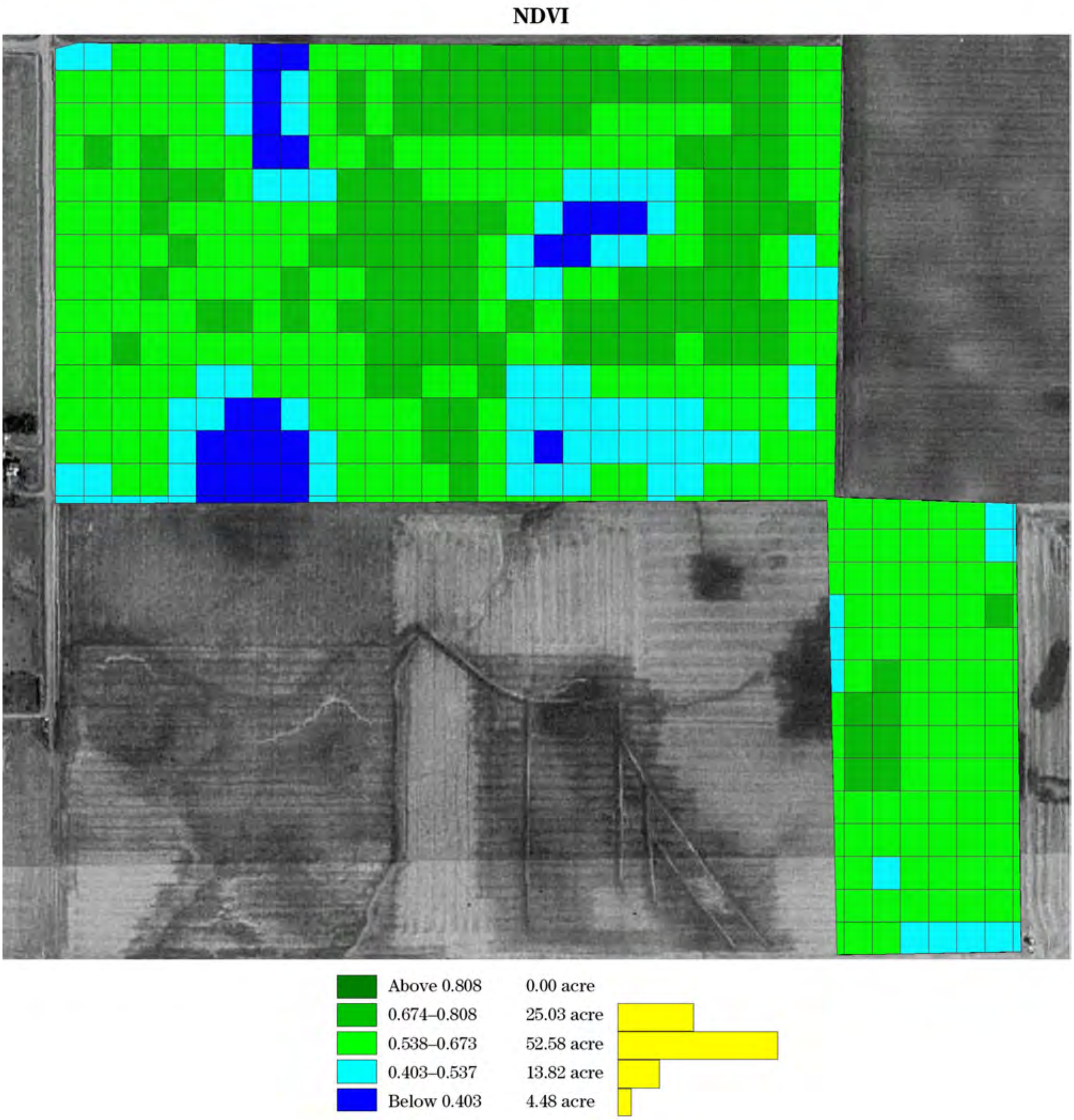

Figure 2 Prescribed (Rx) rate (units N)

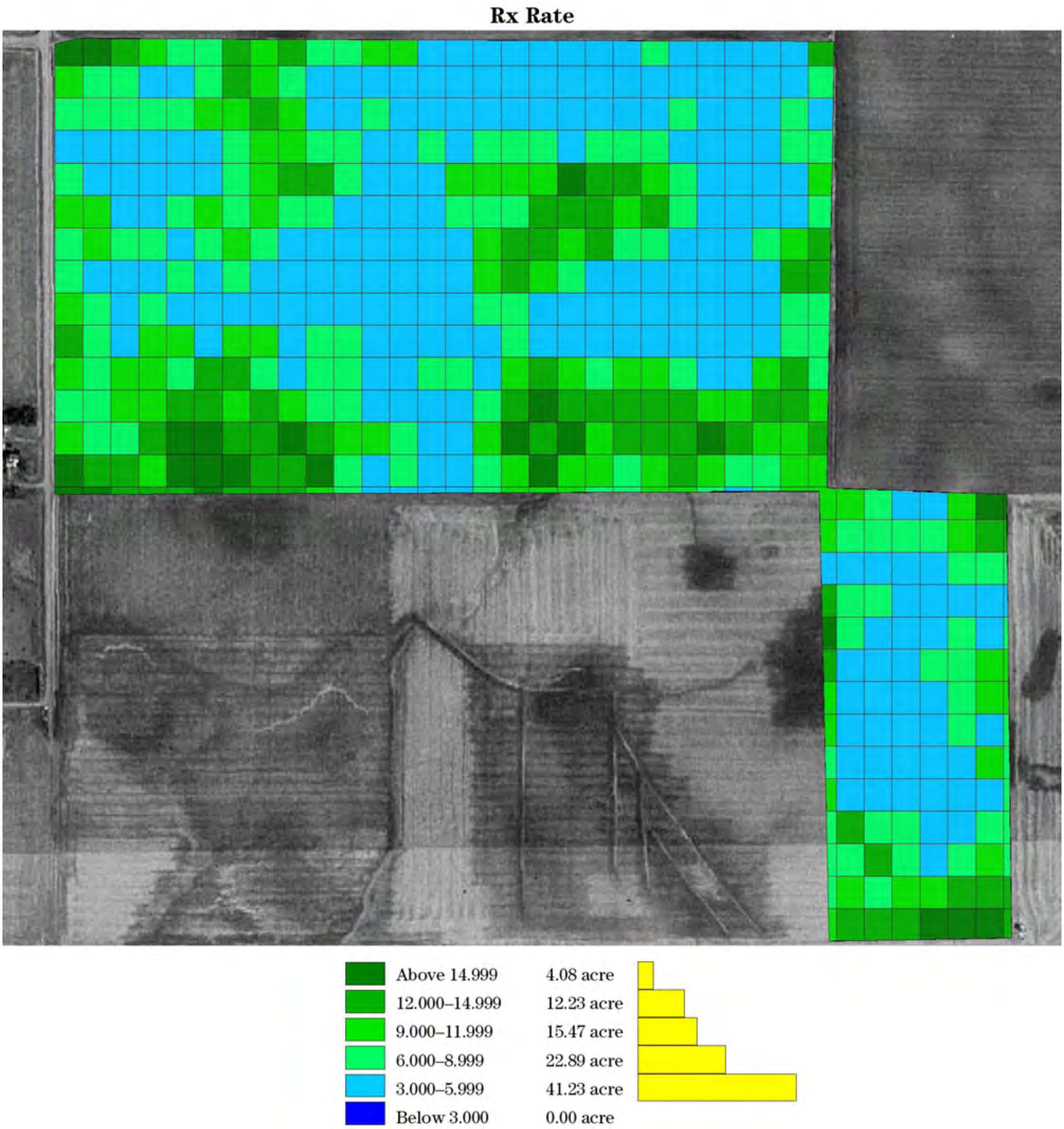

Figure 3 Application rate (units N)

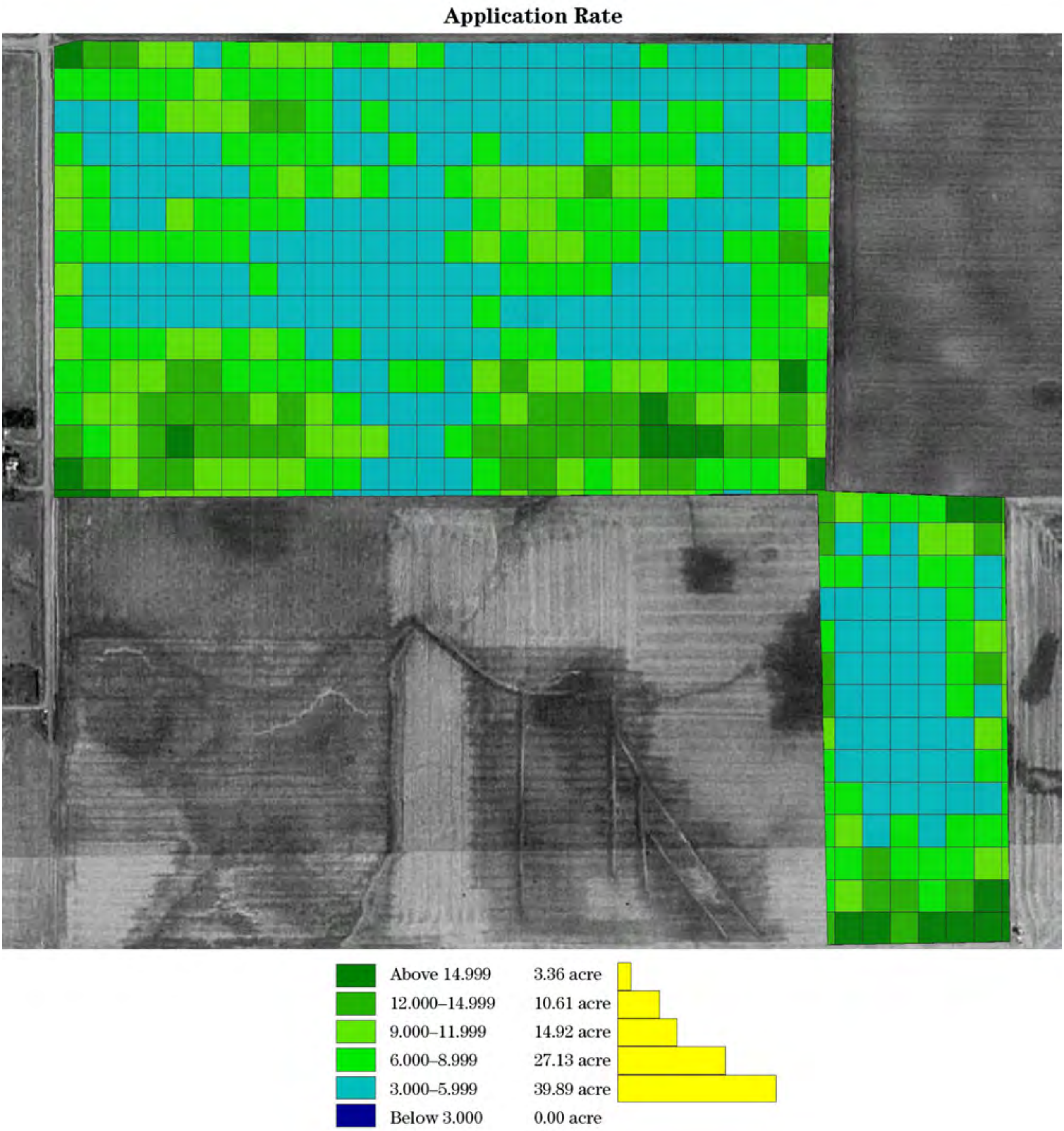

Figure 4 Yield (bu/acre)

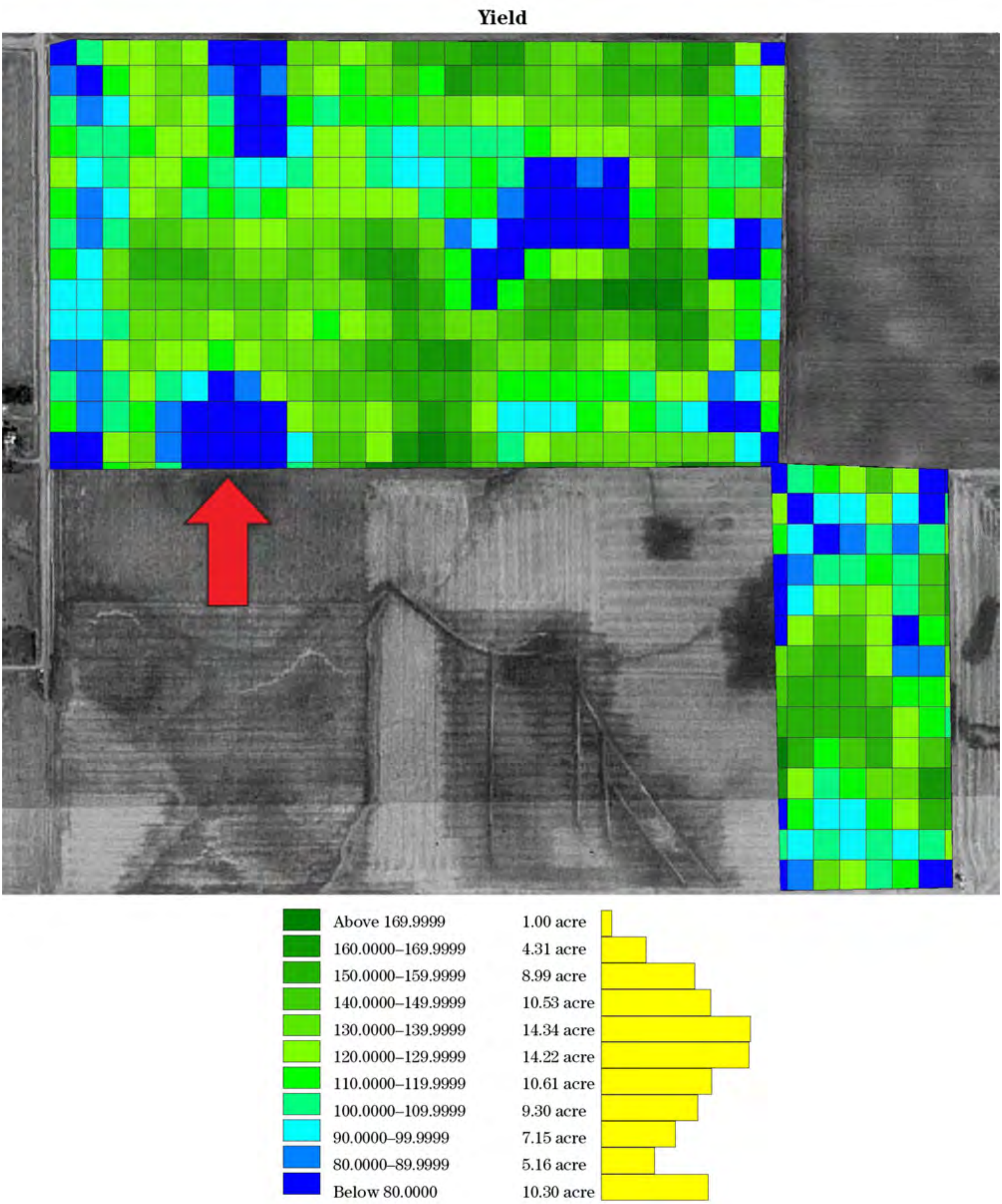

Figure 5 Elevation (ft)