Site-Specific Management Guidelines

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SSMG-2

Management Zone Concepts

Summary

- Varying the application rates of plant nutrients and other crop inputs across variable fields makes good agronomic sense. For every input, some reasonable strategy must be used to guide that application.
- Grid soil sampling for phosphorus (P) and potassium (K) has greatly improved the accuracy of fertilizer application, although even greater accuracy can be attained by considering additional site characteristics within sub-regions of fields.
- A “management zone” is a sub-region of a field that expresses a relatively homogeneous combination of yield-limiting factors for which a single rate of a specific crop input is appropriate.
- Spatial information that is most helpful in defining management zones should be quantitative (numerical), densely or continuously sampled, stable over time, and directly related to crop yield.
- The basis for accurate and profitable application of crop inputs…uniform or variable-rate…will continue to be a clear understanding of the agronomic factors that directly affect crop growth and yield.

Introduction

Precision farming is collecting and controlling agronomic information to supply actual needs to parts of fields rather than average needs to whole fields. Early attempts to variably apply crop inputs were based on grower intuition, soil survey maps, soil test data from sparsely spaced grid samples, and direct observation of soil conditions while traversing variable fields. Continued research has revealed the importance of considering additional site characteristics that exert a major influence on crop yield. Site-specific application of crop inputs is increasingly accomplished by dividing whole fields into smaller, homogeneous management zones. This *Guideline* will discuss how management zones can be defined, the steps for initiating a management zone strategy, and several methods to evaluate the economic effectiveness of management zone strategies.

Variable-Rate Application: Yes…But How?

Varying the rates of crop inputs to meet site-specific needs makes economic and environmental sense. Candidates for variable application include major plant nutrients…nitrogen (N), P, and K…lime, seed rate, hybrid or variety, pesticides, manure, soil amendments, water, and tillage. For each input, a clear strategy must be developed to accurately guide that variable application.

With variable-rate input controllers, growers can spontaneously respond to site variation they observe while traversing a field. An example is the fertilizer spreader operator who manually varies N, P, or K rates in a field based on changes in soil texture or color, quantity of crop residue, landscape position, or other visual features of the field. Unfortunately, varying input rates manually can be very subjective and adversely affected by operator fatigue. Typically, varying crop inputs will be based on some pre-planned strategy that is related to field characteristics.

The aim of any variable-rate input strategy is the development of an accurate “application map.” This is the blueprint that determines the level and location of inputs applied to the field.

Initial Application Maps for P and K Fertilizers

In the early 1990s, application maps were first developed for use with P and K fertilizers based on soil test results from sparsely spaced grid sampling. Because the data from grid soil sampling are sparsely spaced, estimates of soil test values in between the sample points must be interpolated or estimated. Initial grid sampling research focused on sampling density, suitable interpolation techniques, and economic feasibility. This research concluded that sampling density should generally be no more than 2.5 acres for routine plant nutrient sampling, and either kriging or inverse distance interpolation methods are usually the most appropriate. Grid soil sampling has improved the accuracy of fertilizer applica-

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tion in several ways. First, it represents a large increase in spatial information compared to whole-field composite sampling or no sampling at all. Second, it has often exposed spatial features previously unknown about a field. One example would be greatly elevated levels of soil P or K levels in parts of fields due to non-uniform distribution of animal manures from long-discontinued animal feeding operations.

Grid soil sampling also has several technical limitations. First, unguided grid soil sampling patterns ignore what growers already know about their fields through direct experience or from soil survey maps. Second, only the simplest geostatistical methods are considered appropriate for fields containing fewer than 100 georeferenced samples. Third, it appears that the accuracy of interpolated application maps is, to some extent, a matter of chance. The best interpolation technique to use will depend on the unique spatial properties of the data set itself and cannot be predicted in advance. Even the location of samples within the grid cells can greatly influence the appearance and accuracy of the application map. Finally, perhaps the most serious limitation of grid sampling for plant nutrients is the finding that soil test calibration can vary dramatically across soil landscapes. In a typical landscape from the western Great Plains, Westfall and his co-workers found that 56 percent of the sites evaluated along a 1,300 ft. transect did not conform with conventional soil test calibration. Increasingly, agronomists are moving to a "management zone" concept as the basis for varying crop inputs across variable fields.

What Are Management Zones?

Agronomists have attempted to avoid the limitations of unguided grid soil sampling by including other site characteristics when they develop variable-rate input strategies. These include quantitative, qualitative, and intuitive/historical factors, some of which are relatively stable from year to year, and some of which are dynamic (see **Table 1**). In this context, a precision farming management zone is defined as ***"a sub-region of a field that expresses a functionally homogeneous combination of yield-limiting factors for which a single rate of a specific crop input is appropriate."*** Thus, the delineation of management zones is simply a way of classifying the spatial variability within a field. To be successful, the delineation strategy must be based on true cause and effect relationships between site characteristics and crop yield.

Practical Considerations for Defining Management Zones

Intuitively, the more factors included in a management zone strategy, the better the accuracy of the variable-rate application map. Here are several key considerations for selecting site characteristics to include in a management zone delineation strategy.

Relationship with crop yield: The most meaningful factors to include in a management zone strategy will be those with the most **direct** effect on crop yield. Examples include soil moisture relationships, soil pH, soil pathogen infestation, and extremes in soil nutrient levels. Ironically, crop yield patterns from yield maps may not be stable enough across seasons to accurately define management zones without supplemental information. Surrogate data such as soil E.C. or color may lead to erroneous delineations unless they are carefully correlated with factors that **directly** affect crop yield.

Cost of the data: Some sources of spatial data are available for free or at low cost. These include the grower's local knowledge, soil survey maps, aerial photos, and some remotely sensed images that are available on the Internet.

Data that are quantitative and repeatable: Some site characteristics are directly measurable and will not vary appreciably over time, including topography, electrical conductivity patterns, soil color, and other soil physical properties. If these properties are related to crop yield, they will be reliable ways to define management zones. The advantage of this type of information is that it is stable over time and only needs to be measured once.

Density of the data: Densely sampled data sets are much more robust than sparsely sampled sets and will not be subject to problems with interpolation. Smaller management zones can more realistically be defined from dense data layers. Yield maps, digital elevation models (DEM), digitized aerial images, and other sensor-based data sets are all considered dense.

Scale of the data: Spatial data should be collected at a scale that is at least as fine as the scale of the management zones that will be defined. For a typical variable-rate fertilizer spreader, this would

Table 1. Types of site characteristics on which precision farming management zones can be based.

Type of site characteristic	Examples
Quantitative, stable	Elevation/topography, soil organic matter, pH or calcium carbonate ($CaCO_3$), soil electrical conductivity (E.C.), high intensity soil survey maps, surface curvature and hydrological properties
Quantitative, dynamic	Yield monitor data, weed density and distribution, crop canopy appearance or temperature, soil moisture or salinity, soil or plant N status
Qualitative, stable	Soil color, first order Natural Resource Conservation Service (NRCS) soil survey maps (1:15,800 scale), immobile nutrients (e.g. P and K), soil pathogen or pest patterns, depth to subsoil, soil aeration/drainage status
Intuitive/historical	Grower knowledge of field characteristics, overall yield patterns and historical practices, soil tilth and quality, past crop rotations, old field boundaries, land leveling and drainage patterns, subsoil characteristics

usually correspond to a management zone no larger than 30 x 30 feet. The scale of variation in the site characteristic itself will also dictate the scale at which the data should be sampled.

Some Effective Management Zone Strategies

The "best" management zone strategy will vary from region to region and from grower to grower. Soil and crop characteristics, grower expertise and computer literacy, and data availability will all influence the final management zone selection. A list of the site characteristics commonly used to define management zones for a variety of crop inputs is shown in **Table 2**.

Evaluating a Management Zone Strategy

Management zone strategies maximize economic return by optimizing rates of yield-limiting inputs and controlling the adverse effects of weeds and other crop pests. However, if a grower does not use an accurate means of evaluation, the value of a particular strategy may go unrecognized. There are three methods to evaluate the accuracy of a management zone strategy:

- **Historical:** Make a historical comparison to yield or income levels attained with a previous variable rate or uniform rate input strategy.
- **Indirect:** Scientists have conducted detailed research in various locations to evaluate the effect of certain site characteristics on crop yield. Using sophisticated multiple-variable regression analysis, the effect of many factors contributing to yield variation can be estimated. By inference, any factor that is highly correlated with yield is assumed to be an important site characteristic that should be included in a management zone strategy.
- **Direct:** Precision farmers with differential global positioning system (DGPS)-equipped yield monitoring combines can directly compare the value of two management zone strategies using multiple side by side comparisons or the Pioneer Split-Planter Comparison Method (see SSMG #10). With these techniques, alternating strips of the two input strategies are established across an entire field. At harvest, the alternating strips are separately labeled on the yield monitor and are used to prepare a yield difference map. This map depicts the yield advantage of both treatments across the entire field. The yield difference map can be easily converted to an income or profit difference map by applying simple spatial analysis tools within a suitable geographic information system (GIS).

All three evaluation methods have advantages and disadvantages. Historical evaluations are straightforward and essentially free. Unfortunately, such comparisons are easily confounded by year-to-year yield fluctuations and may not give a definitive answer for several years. The indirect evaluation of individual yield-limiting factors with multiple-variable regression techniques is quantitative, but may be of limited value to areas beyond where the research was conducted. Also, multiple-variable regression analysis is beyond the reach of commercial growers due to the high cost of the specialized labor, equipment and analytical services that are required. Direct evaluation of two management zone strategies with on-farm testing is quantitative, spatially robust, and requires no specialized equipment beyond a yield monitoring and mapping system. In addition, it limits grower risk since only half the field will be treated with a new and possibly unproven variable-rate input strategy. Evaluation of management zone strategies should be an ongoing process as new practices, products, and precision farming tools are continually introduced to farmers.

How to Develop a Management Zone Strategy for the First Time

There is a simple three-step process for precision farmers wishing to move from a uniform-rate to a variable-rate input strategy.

1. **Start simple.** Use the spatial information that is the most readily available and represents the best balance between cost and relationship to crop yield. In general, the best quality information is quantitative, densely or continuously sampled, and represents site characteristics that are stable over time

Table 2. Crop inputs that are commonly applied using variable rates and the site characteristics often used to define management zone strategies for these inputs.

Crop inputs	Management zone factors to use
Immobile nutrients (P and K)	Topography/landscape, grid or targeted soil test data, bare soil photo, soil survey maps, soil E.C. map
N and manure	Soil texture, organic matter, yield zones, bare soil photo, soil nitrate-N (NO_3-N), crop canopy reflectance
Lime	Soil pH, buffer pH, soil texture
Gypsum	Grower knowledge, yield patterns, E.C. map, soil tests for pH and sodium (Na)
Seeding rate	Historical yield levels, top soil depth
Hybrid or variety	Topography, yield patterns, grower knowledge, aerial photos for chlorosis, bare soil photo, geo-referenced pest samples (e.g. soybean cyst nematode, Phytophthora root rot, corn rootworm)
Herbicides	Weed maps or visualization, soil organic matter, soil texture
Pesticides	Soil properties, geo-referenced soil samples and scouting reports
Water	Soil texture, topography, soil organic matter, yield zones

(see **Table 1**). Typical spatial data with which to start developing a management zone strategy include grower knowledge, bare soil photos, first order soil survey maps, field topography, and E.C. maps.

2. **Fine-tune management zones:** Over time, add information that further describes the patterns of yield variation within a field. This includes dynamic or qualitative spatial layers such as multiple-year yield maps, crop canopy reflectance or temperature, high-intensity soil survey maps, grid or targeted soil sampling results, geo-referenced crop and pest scouting reports, and landscape relationships. Taking simple color aerial photos of a field at several stages of crop growth can be a very cost-effective way to gather important spatial information.
3. **Evaluate strategy effectiveness:** Use on-farm testing techniques such as the Pioneer Split-Planter Comparison Method to evaluate the performance of two management zone strategies, preferably over multiple site-years. It is crucial to maintain a sound agronomic perspective when evaluating the performance of different management zone strategies. Critically look for primary yield-limiting factors and for possible confounding effects. Be patient – remember that no single strategy will be perfect every year.

Management Zone Delineation in the Future

In the near future, more and higher quality data layers will become available for use in defining management zones. These will include remotely sensed and other digitized images as well as dense data sets from electromagnetic, chemical, and mechanical sensors. The utility of these sources of information will be determined by their cost, relationship to crop yield, and ease of use. Mathematical procedures that recognize spatial patterns contained in multiple-year yield maps may provide a new tool for identifying sub-regions within fields. As always, any method that **indirectly** evaluates yield patterns will be of little value in defining input management zones if it cannot be correlated with factors that **directly** affect yield variability.

For some inputs, variable-rate application maps may eventually be eliminated altogether. Automated sensors that can accurately drive a variable-rate controller may one day fill this role. Currently, sensors are available or are in development to continuously measure the presence of weeds, soil pH, soil NO_3, crop N status, and soil texture/compaction. With the exception of several weed-sensing devices and an E.C. measuring system that varies nutrient applications, there are no commercially available on-the-go sensors being used to control the variable application of crop inputs. Regardless of what new technologies become available in the future, the basis for accurate and profitable application of crop inputs–uniform or variable–will continue to be a clear understanding of the agronomic factors that directly affect crop growth and yield within each growing season. ■

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