Site-Specific Farming Comes of Age: *Managing Field Variability*

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…the farm community doesn't want to be entrapped by a new technology; it wants to be empowered by useful new tools—

Site-specific management, often referred to as "precision farming," means different things to different people— from the pinnacle of farm efficiency, to a vast array of new products and services, to the techno-death-throws of indigenous insight and quite possibly, farming as we know it. In reality, it is likely none of the wealth of individual perspectives, but an amalgamation of them all. All parties, however, appear to agree that this emerging technology is intimidating, confusing, and often misunderstood. This presentation attempts to remove some of the mysteries and misconceptions by outlining the elements of site-specific management, the technical issues surrounding its development, the legal issues and their impacts, and important extended issues and trends driving site-specific management. But first a brief discussion of what site-specific management is (and isn't) is in order.

What Site-specific Management Is (and Isn't)

In essence, site-specific management is about *doing the right thing, in the right way, at the right place and time.* It involves assessing and reacting to field variability and tailoring management actions, such as fertilization levels, seeding rates and variety selection, to match changing field conditions. It assumes that managing field variability leads to both cost savings and production increases. Site-specific management isn't just a bunch of pretty maps, but a set of new procedures that link mapped variables to appropriate management actions. This conceptual linkage between crop productivity and field conditions requires the technical integration of several elements.

Elements of Site-Specific Management

Site-specific management consists of four basic elements: global positioning system (GPS), data collection devices, geographic information systems (GIS) and intelligent implements. Modern *GPS* receivers are able to establish positions within a field to about a meter. When attached to a harvester and connected to a *data collection device*, such as a yield/moisture meter, these data can be "stamped" with geographic coordinates. A *GIS* is used to map the yield data so a farmer can see the variations in productivity throughout a field.

The GIS also can be used to extend map visualization of yield to "map-ematical" analysis of the relationships among yield variability and field conditions. Once established these relationships can be used to derive a "prescription" map of management actions required for each location in a field. The final element, *intelligent implements*, reads the prescription map as a tractor moves through a field and varies the application rate of field inputs in accordance with the precise instructions for each location. The combining of GPS, GIS and IDI (intelligent devices and implements) provides a foothold for both the understanding and the management of field variability.

Smart Farmers, Dumb Maps

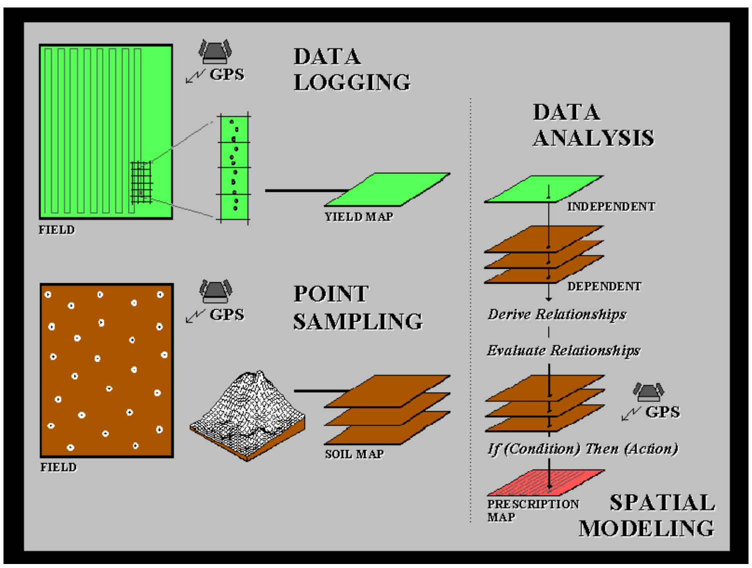
To date, most analysis of yield maps have been visual interpretations. By viewing a map, all sorts of potential relationships between yield variability and field conditions spring to mind. These *visceral visions* and explanations can be drawn through the farmer's knowledge of the field— "I bet this area of low yield aligns with that slight depression," or "maybe that's where all those weeds were," or "wasn't that where the seeder broke down last spring?" Data visualization can be extended through GIS analysis directly linking yield to field conditions.

This *map-ematical* processing involves three levels: cognitive, analysis and synthesis. At the *cognitive level* (termed desktop mapping) computer maps of variables, such as crop yield and soil nutrients, are generated. These graphical descriptions form the foundation of site-specific management. The *analysis level* uses the GIS's analytical toolbox to discover relationships among the mapped variables. This step is analogous to a farmer's visceral visions of relationships, but uses the computer to establish mathematical and statistical connections. To many farmers this step is an uncomfortable "leap of scientific faith" from pretty maps to pure, dense techy-gibberish. However, map-ematical analysis greatly extends data visualization and can more precisely identify areas of statistically high yield and correlate them to a complex array of mapped field conditions.

The *synthesis level* of processing uses spatial modeling to translate the newly discovered relationships into management actions (prescriptions). The result is the prescription map needed by intelligent implements in guiding variable rate control of field inputs. Admittedly, the juvenile science of site-specific management is a bit imprecise, and raises several technical issues.

Technical Issues

The accompanying figure identifies the four basic processing steps in site-specific management. Data collection for site-specific management can be divided into two broad areas: continuous data logging and discrete point sampling. *Data logging* continuously records measurements, such as crop yield, as a tractor moves through a field. *Point sampling*, on the other hand, uses a set of dispersed samples to characterize field conditions, such as phosphorous levels.



The nature of the data derived by the two approaches are radically different—a "direct census" of yield versus a "statistical estimate" of phosphorous. In data logging, issues of accurate measurement, such as GPS positioning and material flow adjustments, are major concerns.

In point sampling, issues of spatial interpolation (estimating between sample points), such as sampling frequency/pattern and interpolation technique, are the focus of concern. In both cases, the resolution of the analysis grid used to geographically summarize the data is a critical concern. If the analysis grid is too coarse, information is lost in the aggregation over large grid spaces; if too small, measurement and positioning errors are influential.

The technical issues surrounding *mapped data analysis* and *spatial modeling* involve the validity of applying traditional statistical techniques to spatial data. For example, regression analysis of field plot data has been used for years to derive crop production functions, such as the corn yield versus potassium curves you might recall from college. In a GIS, you can regress a entire map of corn yield on a map of potassium (they're just spatially organized sets of numbers) to derive the production curve relating the two mapped variables— but should you? Technical concerns, such as variable independence and autocorrelation, have yet to be thoroughly addressed. Statistical measures assessing results of the analysis, such as a spatially responsive correlation coefficient, await discovery and acceptance by the statistical community.

Spatial modeling uses the relationships established during the data analysis phase to determine the "optimal" actions, such as amount of phosphorous to be applied to each location in the field. The issues surrounding spatial modeling are similar to data analysis and involve the validity of using traditional "goal seeking" techniques, such as linear programming or genetic modeling, to generate maps of the optimal actions (prescription maps).

At present, the full map-*ematically* based approach to site-specific management is in the hands of the researchers. Like the "chicken or the egg" dilemma, the skeleton of the site-specific management process is being put in place by a variety of vendors, thus enabling researchers to continuously refine the analytical/modeling meat. Putting aside the considerable technical challenges, what are the major social implications of site-specific management?

Legal Issues and Impacts

Four important social issues surround site-specific management: intellectual property rights, intellectual property wrongs, who owns the data, and data haunting. From the vendor's point of view *intellectual property rights* are a major concern. The issuance of broad patents to individual companies, such as linking GPS to GIS and variable rate control, reward innovative thinking, yet generate market uncertainty and stifle open development of an emerging technology.

Intellectual property wrongs refer to the validity of site-specific management systems. They all generate pretty maps, but whose map is best? And what recourse do you have if you follow a bum prescription map and lose the farm? The need for standards in site-specific management reach far beyond the developer's concern for compatible wiring harnesses and data exchange, to end user needs for assessing system performance and results.

Who owns the data derived through site-specific management is another important issue. If a farmer pays for the collection, analysis and synthesis of site-specific management data about his farm, who owns, and possibly even more importantly, controls access to these data? Can the analyst use or sell the information without the farmer's consent? Or, as with *data haunting*, can the data be used in court against the farmer— sort of a high-tech self-incrimination? As with any new technology, site-specific management is pushing at the envelope of our traditional social beliefs and legal doctrine.

Extended Issues and Trends

Site-specific management is pushing, as well, at current definitions of agricultural research and markets. Historically, *agricultural research* involved controlled studies on a few plots in a couple of fields at a university or experiment station hundreds miles away, involving different soils, climatic conditions and plant varieties. The data was analyzed and the findings published. With the advent of site-specific management, a farmer has access to thousands of "plots" in his own backyard (the analysis grid used in establishing yield and field condition maps). What is needed is a switch in emphasis from publishing research findings to transferring research methodologies so farmers can apply them to their own extensive data sets. Changes in the agriculture market place and the *private/public sector's use of GPS/GIS* are just as dramatic. A clamor for digital mapped data is causing mapping agencies, such as the USGS and the NRCS, to change data collection, map preparation and distribution procedures. Downloading map digital products over the Internet is already a reality, such as maps from the National Wetlands Inventory. A booming cottage industry has sprung up for developing the data bases needed in site-specific management, such as soil nutrient maps. A growing array of options for the tractor, such as GPS and notebook computers mounted in the cab, are rapidly appearing. The proliferation of hardware and software has resulted in a desperate need for *standards*— hardware and data exchange standards are obvious, but data processing standards addressing data errors, conditioning and analysis verge on proprietary "secrete formulas."

However, data processing is what makes radically different maps, and they both can't be right. Without techniques for empirical verification GIS mapping is "like buying a pig in a poke." Consulting services specializing in the analysis of site-specific management data are forming. To date, however, the justification of all this excitement has been on cost efficiency and crop productivity. However, the *natural resources experience* with spatial technologies is much longer and has evolved into a different set of applications. In the beginning, forestry had an operations-centric view similar to the current site-specific management one (in many respects, trees are just 120-foot corn stalks that are harvested every 60 years or so). GIS's automation of mapping and inventory activities promised great savings, and many systems were justified through cost/benefit analysis of operational efficiency. However, the view of GIS as a "tool" expediting traditional management procedures quickly evolved into a different perspective as a radically new "technology" providing entirely new approaches to resource management.

Foresters became familiar with such foreign concepts as optimal path analysis and visual exposure density surfaces, and began applying these tools in innovative ways. More recently, the value of GIS is viewed as not only making more efficient and well-informed management decisions, but as a "revolution" in the decision-making process itself. With the advent of the environmental movement, a forester (vis. farmer) can't harvest a single timber stand (vis. crop) without a thorough analysis of its environmental impacts, such as sediment loading to streams and the health/welfare of wildlife in the area. From this perspective, spatial analysis moves from a cost/productivity focus to a required "license to do business," and bazaar maps, such as the "propensity for litigation," are now as important as timber inventory maps. It's greatest return is as a communication tool in substantiating good stewardship of the land. As increasing environmental regulations loom in agriculture, such as the T-factor in soil loss and nitrogen allocations by watershed, the spatial technologies in site-specific management might become as much a necessity as a tractor— it already has for your backwoods cousins.

Conclusions and Some Good Advice

Site-specific management extends our traditional understanding of farm fields from "where is what" to analytical renderings of "so what" by relating variations in crop yield to field conditions, such as soil nutrient levels, available moisture and other driving variables. Once these relationships are established, they can be used to insure the right thing is done, in the right way, at the right place and time. Common sense leads us to believe the efficiencies in managing field variability outweigh the costs of the new technology. However, the enthusiasm for site-specific management must be dampened by reality consisting of at least two parts: empirical verification and personal comfort. To date, there have not been definitive studies that economically justify site-specific management. In addition, the technological capabilities (cart) appear to be ahead of scientific understanding (horse) and a great deal of "spatial research" lies ahead. That brings us to personal comfort. If you are skeptical of site-specific management and/or feel "cyber-challenged," you should wait to fully adopt the technology. However, keep in mind that if site-specific management proves to be more than a passing fad, its most important ingredient is a robust database — each year that data collection is postponed it puts a farmer farther behind. In the information age, a farmer's ability to react to the inherent variability within a field might determine survival and growth of tomorrow's farms.

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