9th International Conference on Precision Agriculture
July 20-23, 2008, Denver, Colorado

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1) You suggest <slide 4> that there will be a radical change in Ag research from traditional experimental fields to "on-farm studies." How will scientific rigor be maintained and how will the results of thousands of disparate studies be coalesced to advance scientific knowledge?

In the past, most agriculture research involved controlled experiments on trial fields that were analyzed, results summarized and then generalized into recommendations for large geographic regions, such as entire states. In turn these generalized recommendations were interpreted by county extension agents to reflect county variants.

With the increased use of yield and soil nutrient maps individual farms have a robust data set reflecting actual on-farm conditions and results. This suggests that ag research will shift emphasis from generalizing experimental field results to providing the scientific know-how and capabilities that applied to mapped data collected on individual farms. These site-specific results should better represent unique conditions and practices and foster better management actions.

However, the individual on-farm data sets need to be aggregated into extensive databases that can be analyzed at the watershed and regional levels for a broad understanding of crop response, critical factors and stewardship impacts. Ideally, the costs of data collection and on-farm analysis could be partially subsidized for producers who participate in the aggregated program (carrot); or it could be required (stick).

2) "As-applied mapping" <slide 14> suggests an Orwellian spike in bureaucracy for producers. How can production agriculture possibly benefit from yet another layer of controls and paperwork?

Currently a large number of farm inputs require special handling and reporting. Technology exists to extend the reporting to documentation of location and concentration of the actual application—as-applied map. It seems most producers would like to "see" this map instead of simply assuming a prescription map was "perfectly" applied. Effective on-farm studies require detailed actual rather than planed application when relating inputs to outputs (e.g., spatial relationships of PKN applied patterns to Crop Yield patterns throughout a field).

What seems to be the rub is the idea that "government" is intruding on farm operations. However, wise use and stewardship of inputs is assumed …the as-applied map simply documents the fact. A large part of the conflict between agriculture and environmental concerns can be attributed to a lack of objective facts and communication. Without explicit reporting agriculture can't respond to charges of stewardship neglect …with the reporting, false accusation is eliminated for the vast majority; "dead-to-rights" proof for the few offenders.

Most farmers are by their very nature are good stewards of the land (closet environmentalists?). As-applied mapping should confirm this fact …and bring into line those few who are not.

3) If the bulk of agricultural research has been "non-spatial" involving whole-field central tendency assumptions as you suggest <slide 4>, does that mean our scientific knowledge base is outdated and of minimal use in Precision Agriculture applications?

Yes and no. Yes in that surface modeling and spatial data mining techniques respond a continuous geographic distribution of the "variance" in a data set. It uses the detailed information

in the spatial distributions to ascertain relationships within and among map layers. Non-spatial statistics, on the other hand, fails to consider geographic patterns and actually assumes there isn't any spatial autocorrelation in the data (if there is, it means trouble) …everything is assumed to be randomly distributed in geographic space and the average a good indicator of conditions everywhere. The bottom line is that traditional non-spatial analysis falls short of tracking the variation in a field …the foundation of Precision Ag.

However, the non-spatial relationships of traditional research are a good place to start while a spatial knowledge base is being developed. For example, existing decision rules for fertility program levels can be used as a first order estimate of actual field relationships …until on-farm studies establish and assess spatial variability and coincidence relationships. There will be a good bang-for-the-buck by simply expressing non-spatially derived relationships in a spatial manner. Ultimately, "spatially expressing spatially derived relationships" will be the ticket for more accurate management actions.

4) You commented <slide 5> that "smart sampling" techniques are really dumb. Could you elaborate on why that might be the case?

"Smart Sampling" seeks to lower the number of field samples; hence lower sampling costs. While a laudable objective, it has the bold assumption that the stratification of a field into homogenous sampling zones is perfect …this is rarely, if ever, the actual case based on field data I have seen.

There appears to be two primary approaches to implementing Smart Sampling. One focuses on terrain inflections, such as ridges, slopes and bottoms. If dramatic, these characteristics are easy to map and one simply takes a few samples in each zone, then apply the averages back to the entire extent of the respective zones and prepare prescription maps based on the assumption of uniformity within the pre-conditioned delineations. Another approach uses the color differences in an aerial image to pre-condition the field into sampling zones.

Since the terrain and image are both "looking" at just the surface of the field, it is a bold assumption that it accurately reflects the distribution of nutrient, ph, nematode, etc. levels that affect crops a couple of feet or more below the surface.

While pre-conditioned zones assumed in Smart Sampling could be a step in the right direction (management zones vs. whole field), the discrete nature of delineations are problematic. Both approaches assume uniformity within a partition …no or minimal variance, and if present, it is randomly distributed. Since the objective of Smart Sampling is to keep the number of samples low, there isn't enough samples to test this assumption (blind faith is required). Also, the abrupt boundaries tend to "hammer" the control units as sudden application extremes are often encountered.

While Smart Sampling might save a few bucks, it can be really dumb if it fails to accurately portray the true spatial distributions of inputs utilized by plants. An appropriate spatial sampling pattern (that's another story) that is designed to support interpolation of a detailed and continuous grid surface throughout a field is a lot smarter.

5) You suggested <slide 3> that Precision Agriculture is both "following and leading" Geotechnology and that our applications are radically different from the mainstay of GIS applications. In what ways are we following and leading and what future directions do you see that uniquely challenge Precision Ag?

The presentation remarks proposed the idea that Geotechnology is traditionally seen as the amalgamation of three spatial technologies-- RS, GPS and GIS (a cartographer's perspective). However, Precision Agriculture extends the mix to include Data Mining and Robotics-- not the more traditional "map-centric" view of "Where is What" graphical inventories. PA extends this perspective to "Why and So What" by interpreting spatial patterns and relationships (Spatial Data

Mining) for management actions. Robotics provides the ability to play out the decisions "on-the-fly" throughout a field.

The five-sided mix of technologies (RS, GPS, GIS, Data Mining and Robotics) makes Precision Ag fairly unique in its expression of Geotechnology. Add the "cycles and flows modeling" needed for Precision Conservation and agriculture becomes VERY unique--adds Spatial Analysis for a six-sided technological mix (RS, GPS, GIS, DM, Robotics) ...an exciting set challenges and opportunities for redefining agriculture research and management practices. A paradigm shift from maps and discrete non-spatial data to continuous spatial distributions is the keystone to this revolution in agriculture.

However, PA seems to be following in that it utilizes off-the-shelf GIS tools …even in its research applications. As Precision Conservation and spatial analysis procedures take hold there will be a need to develop specialized tools and applications …more direct linkages to Geography, Mathematics and Computer Science expertise on campuses are required to support innovative research and advanced applications.