

Spatial Analysis of Precision Agriculture Data: Role for Extension

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Introduction

Farmers with precision agriculture technologies have an enhanced ability to conduct on-farm trials, thus providing an opportunity for Extension professionals. A three-year case study followed the decision making process of five farmers across the U.S. and Canada who were conducting on-farm trials using precision agriculture and yield monitor technology. Topics relating to the roles of Extension were included in this case study to evaluate 1) if farmer-Extension relationships changed during this project and 2) what role Extension may play in spatial analysis services.

Purdue University has been regarded as an innovator in interdisciplinary precision agriculture. The Site-Specific Management Center (SSMC) was one of the first and few remaining multi-disciplinary initiatives. Some of the first on-farm trials with yield monitors were conducted at Purdue (Lowenberg-DeBoer and Aghib, 1999) as well as the first published use of spatial regression for analysis of on-farm trials (Anselin et al., 2004). Other institutions have partnered with Purdue SSMC for site-specific analysis of on-farm trials (Lambert et al; 2006), even with non-Midwestern crops such as cotton (Griffin et al., 2005) and rice (Griffin et al., 2006). Spatial analysis as used in this paper is defined as explicitly modeling the spatial autocorrelation in a spatial process model capable of making statistical inference. This definition contrasts to other forms of “spatial analysis” which may include some analysis with geographic information systems (GIS), printing yield maps, or arithmetic calculations based on GIS analysis.

Precision agricultural technologies such as yield monitors, grid soil sampling, and automated guidance have been adopted. Corn and soybean yield monitors were used on 15.6% and 13.3% of planted acres in 1996 and exceeded 30% of planted corn and soybean acreage in 2001 and 2002, respectively (Griffin et al., 2004). Wheat and cotton acres have experienced less adoption than corn and soybean with approximately 9% and 1% percent of the acres planted to wheat and cotton, respectively, harvested with machines equipped with yield monitors by the end of 2000 (Griffin et al., 2004). Whipker and Akridge (2007) report that 82% of service providers use GPS guidance with manual control to make custom applications and 29% use GPS automated guidance.

Research on the profitability of precision agriculture technology and adoption has received considerable attention although the results are not consistent. Griffin et al. (2004) reviewed 234 articles and reported that 210 articles presented losses or benefits, with only 68% reporting positive benefits from some sort of precision

agricultural technology. Approximately half (52%) of those studies reporting benefits were written or co-authored by economists (Griffin et al., 2004).

Data and Methods

Qualitative case study research methods have been used in farm management and agricultural business research in general and farmers' use of precision agricultural technology in particular (Griffin, 2006; Urcola, 2003; Popp et al., 2002; Griffin, 1999). Case study methods presented by Yin (2003) were used to evaluate each farmer-collaborator as a unit of analysis during this three-year project. In addition to formal case study research, evidence from a pilot yield monitor data analysis service and two yield monitor data analysis workshops are presented.

Case Study Subjects

The five farmers conducting their own on-farm trials in Indiana, Illinois, Kentucky and Ontario, Canada volunteered to collaborate in yield monitor data analysis case studies during the Top Farmer Crop Workshop (www.agecon.purdue.edu/topfarmer) at Purdue University. Farmers were selected based upon their expertise in conducting on-farm trials with yield monitor technology and were identified as innovators who sought out more appropriate analysis techniques. All five farmers have at least seven years experience utilizing site-specific yield monitor data and testing production practices on their farms.

The five farmers were included in a multiple case study (Yin, 2003) consisting of two groups funded by a United States Department of Agriculture Sustainable Agriculture Research and Education (USDA-SARE) Graduate Student Research Grant. Three farmers introduced to spatial analysis over the three year project period comprise the first case study group referred to as the experimental group. The case study comparison group includes two farmers that did not receive a spatial analysis report prior to the final interview; however, these farmers were not expected to differ from the experimental group with respect to technology adoption, use of precision agriculture, and conducting on-farm trials. The experimental group includes Farmers D, F, and W while the comparison group includes Farmers P and T.

Experimental Group Farmers

All three experimental group farmers have at least seven years experience mapping yields. They test production practices on their farms every year. Experimental group farmers agreed that yield monitor data led to tiling and drainage decisions. At present, yield monitors are being used to fine-tune production systems. In addition, elevation data collected with GPS yield location were often used in on-farm trial analyses.

Farmer D

Farmer D is a sole-proprietorship irrigated producer in Illinois. Soils range from high organic mucks to sands, often within the same field. Topography influences both yields and yield response to input. Due to being a minor soil formation area of the state, limited public research has been conducted that directly impacts production in this isolated region. Crops grown include corn, soybean, popcorn, green beans, and seed corn. The Illinois Farm Business Farm Management Association (FBFM) tracks financial information. Farmer D is a graduate of Illinois State University.

Manual GPS lightbar navigation has been used for four years; however, no automated guidance has been used. Variable rates of lime, phosphorus, and potassium have been made over the past five years. Farmer D has been using computers and Internet for 10 years. His first yield monitor was bought off the back of a flatbed trailer at an auction in 2000 and began collecting georeferenced yield data and using farm mapping software the following year.

Farmer F

Farmer F produces corn and soybean in Indiana. Fields are rolling hills and some eroded hilltops have resulted from conventional tillage practices. All farms have been converted to strip-till production over the past five years. Farmer F is a graduate of Purdue University.

Farmer F has been using computers for more than 12 years and Internet nearly 10 years. Manual lightbar navigation has been used for four years prior to adopting automated guidance four years ago. The highest level of GPS accuracy, RTK-GPS, has been used for automated guidance the last three years and is currently used on four tractors. Yield mapping and farm mapping software have been used for seven years. Variable rate applications of lime, phosphorus, and potassium have been made over the last four years.

Farmer W

Farmer W is a sole proprietorship in Kentucky. Farms are rolling hills with eroded hilltops and depression areas prone to yield loss in wet years. Variability in soils and topography influences yield response by weather year interaction. Farmer W has been practicing no-till corn and soybean production for 20 years; however, many fields were extensively tilled prior to Farmer W management. Farmer W is self described as being skeptical and paying no attention to testimonials for products or services. One characteristic that distinguishes him from many other farmers is his preference to “watch his child’s soccer game rather than sit on a tractor.”

Farmer W has an advanced degree in Agricultural Economics from Purdue University. Lightbar navigation has been used for nine years and automated guidance for two. Farmer W stated that the first piece of farm machinery purchased was a personal computer in 1986 with Internet and email being used for the last four years.

Comparison Group Farmers

The two comparison group farmers have each been mapping yields for at least 13 years. They did not receive a spatial analysis report of their on-farm trials prior to the final interview. However, in other respects, the characteristics of comparison group farmers were not expected to be different from experimental group farmers.

Farmer P

Farmer P farms as a partnership between three brothers in Kentucky all of which have at least a four-year college degree. The farm fields are rolling hills with eroded hilltops. The interviewee has been farming full time for six years as a third generation farmer. Farm management and production decisions are made among family members.

Farmer P has been using computers for farm management for 27 years, with internet over the past ten. Manual lightbar navigation was used four years ago with automated guidance used on equipment for the last two years. Variable rates of lime and seeds have been made for eight and 10 years, respectively. On-farm trials have been a management practice for 10 years.

Farmer T

Farmer T farms corn, soybean, dry edible beans, and wheat in Canada. Farmer T was considered to be an innovator with the first automated boom sprayer in Ontario, mapping yields for 13 years, and using farm mapping software for 12 years. Manual lightbar navigation has been used for four years and automated guidance for two years. Variable rates of nitrogen, phosphorus, and potassium fertilizer have been made for eight years.

Farmer T earned a B.S from University of Guelph and an advanced degree in Agricultural Economics from Purdue University where he began using computers and internet extensively 17 years ago. Locally developed accounting software helps him track farm financial information.

Yield Monitor Data Analysis Service and Workshops

A three-year pilot project was initiated in 2003 for a Yield Monitor Data Analysis Service to be held in conjunction with the Top Farmer Crop Workshop at Purdue

University from 2004 to 2006 (Griffin and Lambert, 2005; Lambert and Griffin, 2004; Lowenberg-DeBoer and Griffin, 2003). The Yield Monitor Data Analysis Service was offered at no additional cost to workshop participants. Each year, workshop registrants received a packet to prepare for the workshop including a cover letter explaining the Yield Monitor Data Analysis Service. Details of the Yield Monitor Data Analysis Service were also on the Top Farmer Crop Workshop website at <http://www.agecon.purdue.edu/topfarmer>. The Yield Monitor Data Analysis Service criteria included that datasets include a planned on-farm comparison. The workshop did not offer data mining analysis of precision agriculture data collected from fields where there was no experiment.

During the three-year case study and pilot Yield Monitor Data Analysis service project, farmers suggested that they had an interest in performing at least some portions of the spatial analysis for their own on-farm trials. In response, the project investigators offered Yield Monitor Data Analysis workshops in November 2005 (Erickson, 2005) and March 2007 (Nistor and Florax, 2007).

Case Study Evidence

Case study evidence was compiled from three sources. The main source of evidence was the result of a three-year case study of five farmers who conduct on-farm trials using precision agriculture technology. Casual direct observational evidence was collected by the researchers over the project period and formal evidence collected during face-to-face interviews at the end of the project (Griffin, 2006). Case study evidence was supplemented by the Yield Monitor Data Analysis Service held in conjunction with Purdue University's Top Farmer Crop Workshop and Yield Monitor Data Analysis Workshops.

Five topics pertaining to Extension were discussed with case study farmers. Topics included 1) farmers' interest in participating in a regional on-farm trial project, 2) farmers' advice for other farmers, 3) expected source of spatial analysis services, 4) farmers' willingness-to-pay for spatial analysis services, and 5) the expected role of Extension.

Participation in regional on-farm trial project

Case study farmers' interest in participating in regional on-farm trials where each farmer provides a replication of the experimental treatments on their farm was not clear. Four of the five farmers expressed interest in direct participation in a regional research project. Farmer D and Farmer P were very interested in regional on-farm trials; potentially to determine if localized response differs from other regions (Table 1). Farmer F was not interested in participating in formal regional on-farm trials but values having a network of colleagues with which to share information (Table 1).

Farmer T aligned with Farmer F stating that two way communication and sharing of ideas was of value (Table 1). Farmer W was willing to participate, but did not have increased interest in regional on-farm trials relative to before this project (Table 1).

Who will conduct spatial analysis

If and when spatial analysis services become common, several possible scenarios exist with respect to the source of the service. Four of the five case study farmers (Farmers D, F, P, and T) suggested that farmers should conduct their own spatial analysis if interest and time were available and farm scale was sufficiently large (Table 1). Three of the five case study farmers (Farmers W, P, and T) suggested Extension may have a primary role in providing spatial analysis services if the farmer opted to outsource to a third party (Table 1). Other third-party sources of spatial analysis may include dedicated private consultants or service packaged along with other agricultural services from providers. Over the last decade, 20 to 30% of service providers surveyed have offered yield data analysis at an average of approximately \$1 per acre fee although several providers responded as not charging a fee for the service (Whipker and Akridge, 2007). It is suspected that the survey question regarding yield monitor data analysis services may have been interpreted as creating or printing yield maps.

Farmers' willingness-to-pay for spatial analysis

Farmers' willingness to pay for spatial analysis services may dictate the source of the service. Case study farmers suggested three different fee structures for spatial analysis including per acre, per experiment, and percentage of net benefit. Suggested per acre fees ranged from \$3 to \$10 per acre while per experiment fees were \$500. With current estimated costs to conduct spatial analysis based on computer software, collecting spatial data layers, assimilating data into a GIS, and in particular human capital costs, fees suggested by case study farmers would not entice qualified analysts to offer the service in the private sector; however, there is opportunity for Extension to offer the service since human capital costs may be considered a public good paid for by tax funds especially in conjunction with a larger program until computational and software limitations are reduced and thereby lowering the analysis costs. A parallel example may include the whole-farm linear programming (LP) modeling service as part of Purdue's Top Farmer Crop Workshop. Purdue University has been able to offer the long-running Top Farmer Crop Workshop due to established synergies and due to its public service. Synergies have existed for 40 years for faculty, staff, and graduate students to interact with innovative large acreage commercial farmers. Graduate students often cite their participation in Top Farmer as a high point in their graduate study and list their contribution as Extension experience on their curricula vitas. Top Farmer Crop Workshop has been an important part of the public service provided by Purdue Extension and as such it is partially supported by tax funds. The LP modeling service has been offered at no additional cost to

workshop participants for over 30 years. The model is expensive to update and requires numerous technical assistants with specialized skills such as professors and graduate students. Assistants help participants input their own farm information and interpret the results. A whole-farm modeling service such as the Top Farmer Crop Workshop LP service would be cost prohibitive in the private sector.

The role of Extension

Some case study subjects suggested that Extension may facilitate much of the opportunity that exists in on-farm trials and spatial analysis including: 1) organize farmer peer group meetings similar to marketing clubs, 2) maintain network of farmers across regions to share information and participate in regional research projects, 3) link to applied researchers, 4) advise on experiment designs, and 5) help farmers select treatments to test. The benefits of Extension facilitating the spatial analysis service include access to unbiased expertise in an existing structure and associated support staff such as graduate and post-doctoral researchers. All case study subjects valued the direct linkage with applied university specialists and researchers. However, case study farmers did not suggest spatial analysis would be directly offered by university Extension programs.

Case Study Farmers' Relationship with Extension

The interviewer noted that several farmers seemed uncomfortable when asked about Extension's role in spatial data analysis, potentially from the interviewer being associated with a university. Specific Extension positions, e.g. educators, agents, or specialists, were never discussed; however, several case study subjects elaborated upon their vision. Case study farmers were interested in campus specialists, i.e. professors and applied researchers, being involved in the spatial analysis process (Table 2). The case study farmers were all educated with at least a four-year university degree and all have had a history of university research being conducted on their farms that developed into relationships with project coordinators at the campus level. Farmers P and W suggested Extension should have an instrumental role in on-farm trials including recommendations on experimental designs and advice on selecting treatments to test. When asked about advice that case study farmers would give to farmers inexperienced with conducting on-farm trials, Farmer W suggested consulting Extension for designing on-farm trial experiments. Farmer W stated that he liked the "multiple university involvement" on his farm. It was expected that experimental group farmers and comparison group farmers differed due to participating with this project. Although experimental group farmers stated an improved relationship with Extension especially with individuals including the principle investigators of this research resulted from participation with this project, comparison group farmers already had close working relationships with multiple universities and stated improved relationships with the principle investigators; thus

farmer relationships with Extension were strengthened from involvement in and intervention by this project.

Evidence from Pilot Yield Monitor Data Analysis Service

In the first year of the pilot project, four farmers with data that fit the criteria had their data analyzed by two agricultural economics graduate students. One farmer brought data but did not participate due to being protective of data. One of the farmers volunteered to present their results to workshop participants. Three farmers either brought data or sent it ahead of time the second year to be analyzed by four agricultural economics graduate students. One farmer who sent the data prior to the workshop were given their results the first day of the workshop and presented their results to workshop participants. In the final year of the pilot program, only one participant brought yield monitor data to be analyzed and according to the workshop evaluations another participant brought data but chose to allocate their time to concentrate on the whole-farm LP model. The farmer that brought data was more concerned with learning their newly acquired mapping software than having on-farm trial data analyzed. Two agricultural economics and one agronomy graduate student assisted spatial analysis in the last year of the pilot project.

In essence, the Yield Monitor Data Analysis Service offered in conjunction with the Top Farmer Crop Workshop was an experiment to determine the demand by farmers for spatial analysis of their on-farm trial data. Although there were no additional costs to participate in the service, very few farmers seemed interested or felt they had the appropriate data. Hypotheses for the low participation were three fold. The first hypothesis was the timing of the workshop which occurs in mid to late July when decisions based on the yield analysis from the previous year's data would have already been made and no new data was available from the major crops. The second hypothesis was that the effort required assembling the complete set of supporting and treatment data for analysis was prohibitive. The third hypothesis was that farmers had a lack of understanding about inferential statistics and what the benefits of rigorous analysis could provide. Although there was a decline in participation in the yield monitor data analysis service over the three-year pilot project, farmers exhibited more interest in learning spatial analysis techniques than having the spatial analysis performed on their data. Therefore, two Yield Monitor Data Analysis Workshops were offered to farmers, consultants, and university personnel.

Evidence from Yield Monitor Data Analysis Workshops

During the workshops, topics related to on-farm trials were discussed including field-scale experimental designs, hands-on yield monitor data filtering and the importance of proper analysis of spatially autocorrelated data. At present, at least five participants have conducted spatial analysis of their own data or as a service for farmers. The principal investigators have been contacted by university research and Extension

faculty in several states, agricultural software industry, and commodity groups concerning advice regarding on-farm trials as well as field-scale researcher managed research.

Rather than conventional promotion techniques, these workshops were announced by project coordinators during presentations such as the Indiana Certified Crop Advisor Conference, and invitations sent directly to the case study farmers and others who had expressed interest in performing spatial analysis for either their own projects or as a service for others. Due to announcements, direct invitations and word of mouth, 30 individuals consisting of farmers including both case study groups, consultants, and university personnel from four US states and Canada attended the workshops.

Case Study Results

The role of Extension may be to facilitate a network of peer farmer groups conducting participatory on-farm research. Although Extension would facilitate the basic network of peers, personal relationships between farmers would be built outside of the Extension framework. Extension professionals would also provide recommendations on specific experimental designs relative to the study field, treatments, and farm management practices. The spatial data analysis service may be facilitated by Extension and possibly offered as an Extension program due to the high costs of specialized human capital in the form of researchers and staffing and the relatively low farmer willingness-to-pay. Two compelling reasons include 1) cost effectiveness of the service and 2) to ensure technical expertise. Universities have sort of a “checks and balances” to continually evaluate qualifications of peers unlike private sector sources which may go unchecked indefinitely. Yield monitor data analysis is expected to lead to more efficient crop production using fewer and more carefully targeted agricultural chemicals and also lead to increased economic activity in rural areas due to more prosperous farmers. Some evidence exists that private groups would offer spatial data analysis (Whipker and Akridge, 2007); although it is unclear if appropriate analysis expertise could be offered at fees farmers are willing to pay.

Under the broad terminology of “spatial data analysis” services currently exist from both private and university sources. Although a yield monitor data analysis service in conjunction with Purdue’s Top Farmer Crop Workshop attracted only a modest number of participants, private “yield analysis” services are growing. It is expected that the free rider problem will surface from private sector firms offering rudimentary services such as printing yield maps under the category of “spatial data analysis” in an attempt to compete with appropriate spatial analyses useful for farm management decision making while providing low quality services at elevated fee structures.

It was expected that Extension’s role includes facilitating regional on-farm trials and potentially providing spatial analysis services or at least interpretation of statistical

results as described in Griffin and Lambert (2005). Rather than training farmers to interpret statistical results, Extension may train private providers of spatial analysis services to analyze data and teach farmers and their advisors to interpret the results.

For nearly 40 years at the Top Farmer Crop Workshop, farmer participants have also been able to use linear programming models to determine whole-farm impacts of changes to their farms. Although farmers are not expected to be able to bring their data to their local county Extension office to be analyzed there or at the respective campus, spatial data may possibly be analyzed at specialized workshops similar to services provided by Purdue's Top Farmer Crop Workshop.

Summary and Conclusions

There are roles for Extension in spatial analysis of precision agriculture and on-farm trial data. At the very least, Extension should offer guidance on selecting treatments to test at the farm-level and designing experiments. Under current costs of offering spatial analysis, no private sector firms are expected to enter the market; therefore, Extension is expected to fill any spatial analysis niche until private providers enter the market. Once private providers of spatial analysis exist, Extension will most likely provide technical training to the private firms in statistical analysis and associated trouble shooting. Regardless of who offers spatial analysis services, Extension is expected to teach farmers and their advisors proper interpretation of spatial analysis results.

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Table 1: Response to Regional On-farm Research Projects, Advice for Other Farmers, and Spatial Analysis Service

Question	Experimental Group			Comparison Group	
	D	F	W	P	T
What is the value in a regional research project?	Would like it	More information good but rather have colleagues to contact with questions	Verifying practices	Extremely high value	Important to share knowledge two-directionally
What advice would you have for farmers considering on-farm trials for the first time?	Be careful with data, calibrate yield monitor. Tend to little details	Make sure devote enough time to trials	Consult Extension researchers for guidance on experimental designs	Prepare for extra time commitment, be patient; garbage in garbage out	Start slow. Do not expect too much. Yield monitors are tools with limitations. Bounce ideas off someone with experience.
Who do you expect to perform the software portion of spatial analysis of on-farm trials?	The farmer	The farmer, some farmers may outsource.	Extension because unbiased. Do not want to send hybrid trials to seed companies.	The farmer depending upon skill level and interest. Probably consultants or Extension.	Centrally located. Large farmers may have someone in-house. Latest research associated with Extension.
What would you expect to pay for full-service spatial analysis?	\$3 per acre	\$5 per acre or \$500 flat fee per experiment. Doubtful to be percentage of expected value.	Percentage of predicted value. Up to several hundred dollars if timely.	\$2 per acre. Maybe on a per experiment basis up to \$500.	\$5 to \$10 per acre or 40 to 50% of payback.

Table 2: Experimental Group Farmers' Comments on Role of Extension

Question	D	F	W
What is the role of Extension?	Supporting role like in marketing clubs, maybe develop yield monitor data analysis clubs by facilitating and setting up farmer peer groups	Doubtful local Extension would have a role or would facilitate spatial analysis or farmer peer groups. Farmers contact individual professors for specific issues.	Recommendations on experimental designs