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PRECISION AGRICULTURE: CURRENT ECONOMIC AND ENVIRONMENTAL ISSUES

Kent Olson

University of Minnesota

University of Bologna	**University of Padova**
University of Perugia	**University of Firenze**
University of Piacenza	**University of Wisconsin**
University of Siena	**University of Alberta**

Precision Agriculture: Current Economic and Environmental Issues[1]

Kent Olson[2]

For the past several years there has been a new hot topic in agricultural circles. This new topic has many names: precision agriculture, precision farming, prescription farming, site specific management, to name a few. I prefer to use the term precision agriculture to refer to all of these ideas; however, a more accurate name for this package of technology and management skills is "information intensive agriculture."

When farmers start talking about precision agriculture, they visualize satellites in space, global positioning systems (GPS), signals going back and forth between the satellites and the GPS, handheld computers and desktop computers, computers on their tractors and combines, computers monitoring their fertilizer and seed inputs and their crop production level by the smallest area possible, geographic information systems (GIS) containing vast amounts of data, the ability to create tables of all kinds of information and colorful maps of their fields, and many other exciting forms of technology. Eventually, farmers also realize this technology comes with a high price, a high requirement of learning new skills, and an uncertain value or benefit to the farm.

After the initial amazement with all the technology, most farmers are left asking, "Is this profitable? Does it pay?" Some farmers with more precision agriculture experience ask the question as Lowenberg-DeBoer and Swinton (1997) have phrased it: "How would we know if (precision agriculture) is profitable?" These farmers have begun to notice how precision agriculture may help them make better decisions, but they have also noticed how many things (hardware, software, systems, and people) need to be changed to obtain those benefits.

Farmers aren't the only ones who ask questions about precision agriculture. Its value is disputed. One group of people thinks precision agriculture is the answer to many of agriculture's problems from farm profitability and viability to environmental quality and sustainability. Another group of people thinks precision agriculture will compound the problems faced by agriculture and people living in rural areas.

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[2]Department of Applied Economics, University of Minnesota, 1994 Buford Ave., St. Paul, MN 55108 USA; phone: 612-625-7723; fax 612-625-2729; Email: kolson@dept.agecon.umn.edu

In the next section of this paper, I develop a working definition of precision agriculture. Then I will start with a rather basic question: why are farmers interested in precision agriculture? I will then go on to discuss some concerns and problems about precision agriculture.

A WORKING DEFINITION

In the U.S., the National Research Council (NRC, 1997) defined precision agriculture as

> "a management strategy that uses information technology to bring data from multiple sources to bear on decisions associated with crop production" (p.17).

I like their basic definition of precision agriculture as a "management strategy." Once one starts learning about all the fancy technological gizmos, it is too easy to think about precision agriculture as merely the purchase of another machine — another combine, another tractor. But, precision agriculture is more than mechanical and physical technology, much more. To receive the full benefits of precision agriculture, perhaps the biggest change is the need to change management style or strategy.

The NRC definition also needs to be broadened to include livestock. We have the technology to monitor the feeding, feed needs, and productivity of individual animals. This ranges from the simple techniques such as feeding the top milk producing cows differently from the lower groups to the identification chips in the neck strap or even embedded in the back of the animal's neck. Similar to the way, crop producers can know where their machines are by the use of GPS, ranchers could keep track of where their animals are on the range. Some livestock producers have also seen the benefits of testing every and all incoming feed sources for nutrient content rather than relying on published average values to develop rations. Thus, livestock production is also involved in information intensive agriculture.

The last change I suggest is to broaden the NRC definition to include more than production. While I won't speak to these functions today, the marketing, finance, and personnel functions of the farm business are also subject to the benefits of a holistic information intensive management strategy.

Thus, I think a better definition is as follows.

> Precision agriculture is the application of a holistic management strategy that uses information technology to bring data from multiple sources to bear on decisions associated with agricultural production, marketing, finance, and personnel.

WHY ARE FARMERS INTERESTED IN PRECISION AGRICULTURE?

The answer is as complicated as farmers themselves. Farmers are both business people and resource managers at the same time. They want to provide for themselves and their families a comfortable standard of living both now and in the future. To them, precision agriculture is a way to obtain more and better information so they can make better decisions and thus better accomplish their multifaceted goals. In many ways, precision agriculture is just the latest way they can improve their management. It seems so new because of the fascinating, space-age technology that it embodies.

The promise of precision agriculture to lower production costs, protect the environment, and allow a farmer to work a large farm creates an intense interest among farmers. Fighting the famous price-cost squeeze forces farmers to seek ways to spread their fixed costs over larger farms. To do so requires speed they say — speed in machinery, speed in information processing, and speed in decision making. Farmers have told me they would operate differently, they'd take more time to evaluate the need for inputs — if they didn't have to cover ground so quickly. Precision agriculture could allow them to use a computerized decision aid and operating system for application and still maintain speed for covering ground and maintaining their standard of living.

PROFITABILITY

Profitability of precision agriculture is the largest concern listed by farmers, equipment developers, and researchers. We have the technology to do many of the ideas embodied in precision agriculture, but the question remains at what cost and what benefit. Several studies have evaluated profitability in the past, but since this is such a young, changing technology, those studies are often out of date before they are published. Lowenberg-DeBoer and Swinton (1997) review several published studies of precision agriculture and found mixed results for the profitability question and results that were tied to a specific location.

In their focus groups with Michigan farmers, Swinton, Harsh, and Ahmad (1996) found farmers were interested in precision agriculture especially if the costs were modest. The farmers were concerned with farm-level profitability and the risk of equipment incompatibility and obsolescence. Swinton and Ahmad discuss how the unexpected costs (learning, incompatibility, early obsolescence, and repair delays) and underestimated benefits need to be included, but they do not make a broad conclusion.

Several studies support the idea that increased variability in the resource (soil fertility, for example) or problem (weed infestation, for example) provides a higher return to precision agriculture. Using a bioeconomic model of weed control, Oriade et al. (1996) found that increasing weed populations and, especially, weed patchiness increased the benefits of precision agriculture practices.

Hennessy, Babcock, and Fiez (1996) found that average fertilization levels chosen under uncertain information on the exact crop needs are likely greater than the levels chosen with site-specific information. They also found, however, that input use under a site-specific system may decrease substantially, but the production and profitability impacts may not be large.

Another problem that needs to be considered is mentioned by Weiss (1996) who argues that the traditional and even advanced treatment of risk is insufficient for precision agriculture because of the spatial dimension. Weiss suggests spatial statistics (e.g., Cressie 1991; Arlinghaus 1996) and spatial econometrics (e.g., Anselin 1988) as potential tools for analyzing precision agriculture.

Much of the previous economic work has missed what I see as the value of precision agriculture — the holistic view, the change in management style. Most of the previous work has focused on only one of many pieces: nutrient management, variable rate seeding, etc. The NRC has it right: precision agriculture is a management strategy, a holistic management strategy. To capture this aspect or value of precision agriculture, it should to be evaluated at the whole-farm level rather than at the practice, field, or machine level.

A more comprehensive view of precision agriculture is as an improved management information system (MIS) that is a product of an investment in mechanical technology. Traditional benefit-cost analysis does not capture the full impact of an investment in information technology since the profitability of an improved MIS comes from improved managerial decision making not just as improvements in easily seen efficiencies (Hamilton and Chervany 1981, Lincoln and Shorrock 1990, Kleijnen 1980, Parker et al. 1988; Banker and Kauffman 1989). Hence, the analysis methods for determining the value of information should be different from a mechanical technology that makes a change in a mechanical process.

A very recent example of the use of value of information in agriculture is Verstegen's (1998) analysis of a MIS for pig farms in the Netherlands. He used positive approaches to derive MIS benefits from the actual decision making of farmers via surveys, panel data, and economic experiments.

Other approaches to analyzing precision agriculture come from general business. Business has developed a set of tools for improving production processes including but not limited to quality control, process control, value analysis, and value chains. Schueller (1993, 1996) has compared precision agriculture to the business management techniques of just-in-time (JIT) and computer integrated manufacturing (CIM). These techniques are described in many business management textbooks (e.g., Schroeder 1993; Schonberger and Knod 1997). Precision agriculture can be analyzed with these techniques to discover whether it is a profitable technology, what parts of the technology are profitable, and how precision agriculture can be improved.

The implementation of precision agriculture on the ground will require development of new decision tools not readily available now. As Lowenberg-DeBoer and Swinton (1997) point out, automated decisions may be required to allow precision agriculture technologies to be adapted in an easier, less labor intensive process. This will require more management preparation before field operations begin — more preparation in terms of how decisions will be made, what variables will be included, and what rules will be specified. These real-time decision packages may include aspects of: dynamic programming (e.g., Zacharias, Huh, and Brandon 1990; Burt and Allison 1963; Burt 1965; Kennedy 1986); Bayesian techniques (Babcock, Carriquiry and

Stern 1996); feed forward neural network (Joerling, Li, and Young 1994).

Farmers have shown a willingness to accept and use automated decision aids, even "black boxes," if they accept the validity and accuracy of the model and data embedded in the black box and respect the reputation of the developer. One farmer expressed the preference for a black box over trying to interpret field maps; this goes back again to the expressed need for speed during operations and the desire to spend management time and skill on other aspects of the business and life beyond farming.

ADOPTION PATTERNS

The adoption process for precision agriculture is difficult to predict. It is not a single technology but a suite of management strategies, technologies, and practices used to improve agricultural decision making that can be chosen in many different combinations of products and services. Farmers will use them in various combinations depending on variations in geography, production systems, and the farmers themselves.

Lowenberg-DeBoer (1997) contends that precision agriculture will not fit the classic S curve model of technology because the technology is immature and lends itself to tinkering, public and private institutions are not yet prepared, and, especially due to the changes in farm policy, risk is increasing in agriculture. He believes the adoption of precision agriculture will be a bumpy ride like the tractor, and, similar to hybrid seed, precision agriculture may not be readily and widely adopted until someone beyond the farmgate puts together a package of products and services rather than expecting the farmer to do some work (such as map development and interpretation).

FARM AND RURAL STRUCTURE

The adoption of precision agriculture is unlikely to be uniform across farm types and sizes. All farm sizes will likely have access to some techniques, but not all farms will have access to all precision agriculture techniques. The NRC notes that "experience with earlier information-intensive agricultural technologies, such as integrated pest management, indicates that in the long term there should be relatively few, if any, systematic differences across farm size in either access to or advantage from precision agriculture implementation" (p.12). The NRC continues their argument that smaller farms should be able to buy services from consultants which are too expensive to purchase internally. However, in the short-run, there may be a shortage of consultants causing the consultants to concentrate in areas of higher demand.

On this point, I think the NRC is not right, they don't evaluate quite hard enough. Integrated pest management is not the same kind of technology as precision agriculture. I think precision agriculture will have a bigger size distributional impact than the NRC describes.

On this size question, I am reminded of Vernon Ruttan's question of several years ago: "Why are farms so small?" With precision agriculture, I think some of the last hurdles to the size constraints are disappearing. The same information technologies that will allow a manager to analyze information and make decisions at a small scale will allow a manager to analyze information and make decisions at the large scale. Better managers will be able to lower costs and improve efficiencies on larger operations and, thus, allow them to gain market share. Hence, I expect farms to grow with the adoption of precision agriculture. However, given the other economic pressures that farmers currently face (e.g., low prices and low income), the impact of precision agriculture may be hard to separate out as a single effect.

On the employment side of the question, precision agriculture will require many new jobs in the rural areas, but "the capability to integrate and support the hardware and software tools of precision agriculture is currently lacking in rural communities" (NRC, p.13). Whether this needed human expertise will come in the form of humans located in rural areas, in the form of human-capital products (e.g., black boxes), or in combinations remains to be seen.

ENVIRONMENTAL QUALITY

Improvement in environmental quality may come simultaneously with improvements in farm profitability — once that level is reached. By applying inputs in the exact, needed dosage on the exact areas or animals needed, costs can be decreased, profits improved, waste eliminated, and the potential for environmental damage reduced.

However, some field studies suggest that the total amount of fertilizer, for example, may not be reduced on a field basis but it will be reallocated from areas of low response to areas of high response. Thus, the direct fertilizer bill does not decrease for the farmer even though the costs of precision agriculture are added. Since the variations in weather may not allow a farmer to benefit fully from this fertilizer reallocation, the farmer may be left wondering whether precision agriculture is personally worthwhile — especially if this happens in the first few years.

Another way in which the environmental benefit may be seen is the ability to specify in a integrated system, those areas where certain chemicals may not be applied at all or at lower rates. For example, setbacks from surface water and ground water inlets can be specified as no-spray areas and the technology of precision agriculture would allow them to be avoided automatically as the farmer covered the rest of the field. This setback could certainly be done visually without this new technology, but the new technology complements farmers' interest in covering ground quickly while at the same time providing environmental benefits to themselves and the public.

DATA OWNERSHIP AND CONFIDENTIALITY

As noted earlier the value of information intensifies with precision agriculture. The data has value for the farmer directly, and has additional value for research, testing, evaluation, and marketing when aggregated with other farmers' data. For this to happen several things need to be developed "including data collection and transfer standards; institutions for collecting, managing, or networking data; and policies to facilitate data sharing and access while protecting proprietary interests and confidentiality" (NRC, p. 7 and 111). In much the same role as farm business record associations have collected and summarized financial data for many years, new associations can be formed, or new activities for old associations can be developed, to capture this value. At this point in time, I have noticed these associations forming as loosely organized clients of individual crop consultants and not part of any public organization. This activity leads right into the concerns over intellectual property, data ownership, and data privacy rights which have not been settled yet.

THE PUBLIC ACADEMIC ROLE

The NRC report identifies several other goals of needs from a public perspective but I close my paper with two that are pertinent to we as academics. The first is the need for new approaches to research to improve our understanding of the complex interactions between multiple factors affecting crop growth and farm decision making (NRC, p.3 and 101). Precision agriculture needs more than the traditional, one-treatment research projects. Second, new curricula and teaching methods for the interdisciplinary approaches underlying precision agriculture need to be developed (NRC, p.5 and 104). Certainly, the case method and active learning will be part of this together with an expansion of the interdisciplinary nature of the learning process.

CONCLUDING COMMENTS

Some people describe precision agriculture as too expensive, too complicated, too reliant on technology, too detrimental to farm and rural structure. It is true that many of the same goals listed for precision agriculture could be done without all the technology. But precision agriculture is in our future. In fact, parts of it are being adopted now. The question is what form and combination of mechanical, physical and information technology will be used.

With the increasing complexity of farming, the increasing risk farmers are exposed to, and the increasing pressure to lower production costs, the management need is for improved information technology, greater information processing capability, and better decision aids. That is information intensive agriculture or precision agriculture.

Thank you.

REFERENCES

Anselin, L. Spatial Econometrics: methods and Models. Dordrecht: Kluwer Academic Publisher, 1988.

Arlinghaus, S.L. ed. Practical Handbook of Spatial Statistics. Boca Raton: CRC Press, Inc., 1996.

Babcock, B.A., A.L. Carriquiry, and H.S. Stern. 1996. An evaluation of soil test information in agricultural decision making. Working paper 96-WP 147, Center for Agricultural and Rural Development, Iowa State University, Ames Iowa.

Banker, R.D., and R.J. Kauffman. 1989. Quantifying the business value of information technology: A conceptual framework and application to electronic banking. Working paper #219. New York: Center for Research on Information Systems, New York University. 27 pp.

Burt, O.R. 1965. Operations research techniques in farm management: potential contribution. Journal of Farm Economics, 47(5):1418-26.

Burt, O.R., and J.R. Allison. 1963. Farm management decisions with dynamic programming. Journal of Farm Economics, 45(1):121-36.

Cressie, N.A.C. Statistics for Spatial Data. New York: John Wiley & Sons, Inc. 1991.

Hamilton, S., and N.L. Chervany. 1981. Evaluating information system effectiveness — Part I: Comparing evaluation approaches. MIS Quarterly, 5:55-69.

Hennessy, D.A., B.A. Babcock, and T.E. Fiez. 1996. Effects of site-specific management on the application of agricultural inputs. Working paper 96-WP 156, Center for Agricultural and Rural Development, Iowa State University, Ames Iowa.

Joerling, W., Y. Li, and D.L. Young. 1994. Feed forward Neural Network Estimation of a crop yield response function. Journal of Agricultural and Applied Economics, 26(1):252-263.

Kennedy, J.O.S. 1986. Dynamic Programming: Applications to Agriculture and Natural Resources. London: Elsevier Applied Science Publishers, 341 pp.

Kleijnen, J.P.C. 1980. Computers and Profits: Quantifying Financial Benefits of Information. Reading MA: Addison Wesley, 262 pp.

Lincoln, T.J., and D. Shorrock. 1990. Cost-justifying current use of information technology. In Managing Information Systems for Profit, T.J. Lincoln, ed. New York: Wiley, p. 309-330.

Lowenberg-DeBoer, J. 1997. Bumpy road to adoption of precision agriculture. Purdue Agricultural Economics Report, November, 1997. Purdue University Cooperative Extension

Service, West Lafayette, Indiana.

Lowenberg-DeBoer, J. and S.M. Swinton. 1997. Economics of site-specific management in agronomic crops. Chapter 16 in The State of Site-Specific Management for Agricultural Systems. F.J. Pierce and E.J. Sadler, editors. Madison, WI: American Society of Agronomy, Inc.

Lowenberg-DeBoer, J. and S.M. Swinton. 1995. Economics of site-specific management in agronomic crops. Staff paper 95-62, Department of Agricultural Economics, Michigan State University, East Lansing, Michigan.

Oriade, C.A., R.P. King, F. Forcella, and J.L. Gunsolus. 1996. A bioeconomic analysis of site-specific management for weed control. Review of Agricultural Economics, 18(1996):523-535.

Parker, M.M., R.J. Benson, and H.E. Trainor. 1988. Information Economics: Linking Business Performance to Information Technology. Englewood Cliffs NJ: Prentice-Hall. 287 pp.

Schonberger, R.J. and E.M. Knod, Jr. 1997. Operations Management: Customer-Focused Principles. 6^{th} ed. Chicago: Irwin.

Schroeder, R.G. 1993. Operations Management: Decision Making in the Operations Function. 4^{th} ed. New York: McGraw-Hill, Inc.

Schueller, J. (Chair). 1993. Working group report. In Soil Specific Crop Management. P.C. Robert, R.H. Rust, and W.E. Larson, eds. Madison WI: American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. Pp. 181-196.

Schueller, J.K. 1996. Impediments to spatially-variable field operations. Computers and Electronics in Agriculture, 14:249-253.

National Research Council, Board on Agriculture, Committee on Assessing Crop Yield: Site-Specific Farming, Information Systems, and Research Opportunities. Sonka, S.T., M.E. Bauer, E.T. Cherry, J.W. Colburn Jr., R.E. Heimlich, D.A. Joseph, J.B. Leboeuf, E. Lichtenberg, D.A. Mortensen, S.W. Searcy, S.L. Ustin, and S.J. Ventura. 1997. Precision Agriculutre in the 21st Century: Geospatial and Information Technologies in Crop Management. Washington, D.C.: national Academy Press.

Swinton, S.M., S.B. Harsh, and M. Ahmad. 1996. Whether and how to invest in site-specific crop management: Results of focus group interviews in Michigan, 1996. Staff paper 96-37, Department of Agricultural Economics, Michigan State University, East Lansing, Michigan.

Swinton, S.M., and M. Ahmad. 1996. Returns to farmer investments in precision agriculture equipment and services. Staff paper 96-38, Department of Agricultural Economics, Michigan State University, East Lansing, Michigan.

Verstegen, J.A.A.M., R.B.M. Huirne, A.A. Dijkhuizen, and J.P.C. Kleijnen. 1995. Economic value of management information systems in agriculture: A review of evaluation approaches. Computers and Electronics in Agriculture, 13(4):275-290.

Verstegen, J.A.A.M. 1998. Economic Value of Management Information Systems in Pig Farming. PhD thesis, Department of Economics and Management, Wageningen Agricultural University, Hollandseweg 1, 6706 KN Wageningen, The Netherlands.

Weiss, M.D. 1996. Precision farming and spatial economic analysis: Research challenges and opportunities. Paper presented at the American Agricultural Economics Association annual meeting, San Antonio.

Zacharias, T.P., M.Y. Huh, and D.M. Brandon. 1990. Information in a dynamic management model: An application to plant-tissue analysis and fertilisation scheduling. European Review of Agricultural Economics, 17:85-97.