The Beginning…

> The farmer of tomorrow is more likely to push a pencil than pull a plow, says Purdue University agricultural economist Mike Boehlje.
>
> "The new agriculture will require new skills," Boehlje says. "The skills will be more those of a general manager, with expertise in employee relations, marketing and strategic planning. That may not appeal to a guy who likes driving the tractor," he says. "In the past, hard assets were prized land, machinery and equipment. The new structure will value knowledge, information and relationships more." (by Chris Sigurdson, Purdue News Service)

As participants in probably the second-oldest human industry (after tool-making), farmers are often typecast as conservative, hopelessly wedded to traditional practices. In reality, farmers are constantly looking for ways to boost production, reduce inputs of labor and chemicals, and build margins while producing a wide range of crops. Probably nowhere is this sense of innovation and experimentation stronger than in North American agriculture, where farm products still compete aggressively on a world market and contribute a substantial surplus to our national balance of payments.

Agricultural managers have for decades taken advantage of new technologies, which enabled better management decision making and improved economic efficiency of operations. Just consider the three prior agriculture revolutions. The first occurred thousands of years ago when animals were employed to till the ground. The second started just over a century ago when animal power was displaced by mechanical power. The third revolution started fifty years ago when synthetic chemicals and hybrid seeds entered widespread use. We are now at the dawn of the fourth revolution; the information revolution. The technology is called precision agriculture, site-specific agriculture, farming-by-the-foot, and information intensive agriculture. Any one of these terms describes the same process and many times are interchangeable. With the adoption of precision agriculture, the extent and rate of change now occurring in development of information have opened the way for significant change in crop production management and agricultural decision-making.

The promise

Precision agriculture is a phrase that captures the imagination of many concerned with the production of food, feed, and fiber. The concepts embodied in precision agriculture offer the promise of increasing productivity while decreasing production costs and minimizing environmental impacts. Precision agriculture conjures up images of farmers overcoming the elements with computerized machinery that is precisely controlled via satellites and local sensors and using planning software that accurately predicts crop development. This image has been called the future of agriculture.

The technologies and practices of precision agriculture offer the potential to fundamentally alter agricultural decision-making. The use of large machinery and hired labor has caused many farmers to think of large fields as the basic management unit. Even though farmers know from experience that yields are higher in some parts of the field than in others, conventional management practices have focused on applying inputs at a uniform rate to an entire field. In particular the description of field variability is highly complex, because it takes place in a natural environment and includes many unknown variables (weather, pest and diseases, etc.). This new technology permit the modern grower to obtain detailed explicit information at a small scale common to farming practices of earlier times but with considerably more information, enabling them to efficiently manage the land at these finer scales. (National Research Council (NRC 1997))

Kent Olson, a University of Minnesota professor of Applied Economics, defined precision agriculture as; "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." This definition emphasizes the idea that precision agriculture is not just a purchase of another machine but is much more a change of management style or in this case "management strategy".

Decision making

A farm manager has to make many decisions that are based on values and beliefs. General agriculture uses three types of decisions making:

1. *Strategic*- defined as a "*skill in managing or planning*" . This decision making process will occur year to year and the goal will affect the whole farm enterprise and is likely to be personal goal to an individual farm manager.

2. *Practices*- defined as "*to do something repeatedly in order to become proficient.*" This management option applies to the family farm operations. Family farms adopt this practice; sons emulate their fathers' successful ways and sometimes are reluctant to adopt new practices.

3. *Operational*- defined as "*a procedure that is part of a series in some work or plan.*" This is farmer proven operations that leads to successful crop production practices. These entail certain tillage, planting, and weed control on individual fields.

Any decision requires a certain amount of information acquisition in order to support itself. Usually farm managers make these decisions based on their education and experience. In addition, they tend to establish their decisions beforehand by searching for advice among their farming community.

According to the National Research Council, (NRC 1997), precision agriculture adds additional components to the decision making formula, but as you look at this list, farmers start to see the complexity of adoption of a new technology.

1. *Capture of data-*
    a. At an appropriate scale and frequency.
    b. The type of data to capture
        i. Yield data
        ii. Soil test
        iii. Soil texture

iv. Remote sensing
v. Landscape
vi. Others…

2. *Interpretation and analysis of that data*
    a. Statistical
        i. Kriging
        ii. Inverse Distance
        iii. Nearest Neighbor
        iv. Others…
    b. Farm induced intuition

3. *Implementation of a management response at an appropriate scale and time*
    a. Spatial
    b. Temporal

The most significant impact of precision agriculture is likely to be on how management decisions address spatial (*happening or existing in space*) and temporal (*a limit of time*) variability in crop productions systems. A key difference between conventional management and precision agriculture is the application of modern information technologies to provide, process, and analyze multi-source data of high spatial and temporal resolution for decision-making and operations in the management of crop production.

Assessing Variability

In crop production, the focus of precision farming is on site-specific crop management. The goal of site-specific crop management is to identify the variability within a field, and then manage crop production according to the localized conditions identified. Site-specific crop management is now becoming possible because an emerging group of technologies allow farmers to change input application rates or types as equipment moves across a field.

Site-specific crop management is a two-step process:

1. Assessing variability

2. Managing that variability

Site-specific crop management is only useful if variable areas within a field:

1. Can be identified

2. Are large enough to matter

3. Are consistent from year to year

Unlike some early adaptors of precision agriculture, this technology is best considered a suite of technologies rather than a single technology. Early on, many farmers thought precision farming was only grid soil sampling and variable rate fertilizer application. This one aspect was a cure-all for their production woes. They failed to take in consideration the numerous characteristics of crop production and when this was the only precision farming practice, farmers were discouraged with this technology. Farmers need to understand the complexity of agricultural production and according to Dr. Noel W. Anderson; established 40+ factors influencing crop production and yields;

Soil	Weather	History	Live Things
Soil type	Rainfall amount	Farmsteads	Insects
Topography	Rainfall timing	Fence lines	Rodents
Organic matter	Hail	Manure piles	Large mammals
N-P-K	Heat & Cold	Past crops	Weeds
Micro-nutrients	Sunlight	Tillage	Fungus
PH	Growing season length	Compaction	Bacteria
Salinity	Drying winds	Erosion	Virus
Moisture	Intense winds	Irrigation	Worms
Shading	Snow melt	Chemical carry-over	Nematodes
Clay pan depth		Tiling & Drainage	

Table 1

As farmers study this table (table 1), they soon realize many of these items they have no control over. One example would be weather conditions, they may implement practices such as irrigation or improved field drainage to help offset some of the extremes of the weather.

All of these components have the common features of increasing the information intensity of agriculture. Focusing on one of these aspects (such as variable rate fertilizer), will only lead to failure for the precision farmer.

The past...

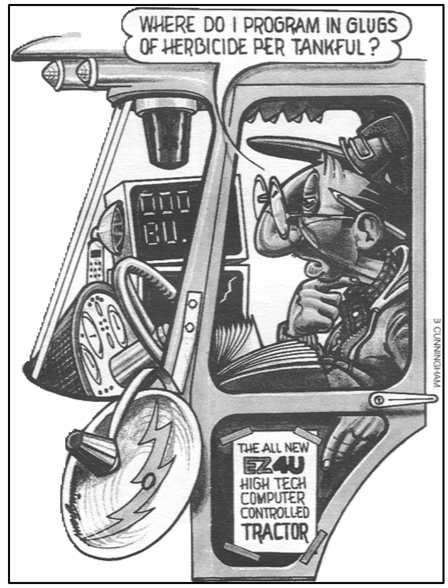
But before we get to engross in the future, we need to understand the past. This article was featured in a Terra monthly new letter, some time in 1995. The author was John Phipps, he showed the awaiting changes agriculture was about to encounter.

The Demise of Approximate farming

A skill farmers have long been polishing is about to become useless, buried under an avalanche of technology. Referred to, of course, is approximate farming. This ability actually comprises several skills developed to answer the age-old agriculture question, “What was the average yield for that field?”

It used to be a world of round numbers—80 acres, $2.00 per bushel, or 1,000 pounds. The first hint of change was the governmental accuracy demanded by the former ASCS, now known as the FSA office. A field that once was thought of 40 acres became 38.8 acres. But for the most part, farmers continue to think of it as 40 acres, since it was an easier number to work with, but eventually farmers started multiplying and dividing by 38.8.

Bookkeeping was done on seed corn pocket notebooks, using numbers like 250 or 45—not 38,750 or 6,661. Farmers could figure in their heads what a 5-bushel yield increase would mean at the end of the year and come close. Small calculations were found on the backs of envelopes and bin walls—cute little number that now looks like a kids sneaker budget. Actual annual profit was revealed by the tax preparer in February, like a doctor announcing the results of an operation. Amazingly, the system was sufficient for the day.



Chemicals were added by glugs per tankful. Seeding rates were crudely adjusted by sloppy mechanisms, but the actual results were unknown anyway, since they had estimated the amount of seed as they scooped it from the bin. And when farmers did measure planting rates, they were measured in bushels per acre, not viable seeds per acre.

The most painful leap of technology was the shaft speed monitor on a combine. One of the few good by-products of combine-seat time was being able to recognize what that sound meant, what that vibration warned. The combine became an extension of a farmers own sensory system. The readings were actually feelings—that vibration meant the fans was going too slow, and that rumble meant grain was probably going over the sieves.

But then a small box made the most inexperienced operator just as capable to detect something amiss. Symptoms were announced with numerical precision, bombarding a farmer with data. Alarms sounded and digits danced, eliminating the need for experience, or intuition, leapfrogging the inexperienced to new levels of competence.

One of the most difficult crop production skills to master was applying anhydrous ammonia accurately. Watching the gyrating pressure gauge, estimating speed from the 4020's juggling mph indicator, and measuring volume by the wonderfully accurate (if even operational) tank gauges meant if your came within 20 to 30 pounds per acre your were a "Master Operator." Wild temperature fluctuations when applying added that element of chaos necessary to make this job a guess when done right, and a breath-taking fertilizer bill surprise when done wrong.

The cruelest blow to such hand-grenade agriculture came in 1994, when a farmer first saw a yield monitor demonstration. For the non-technophobe, it made the rule-of-thumb blood run cold.

Prior to 1993, a farmer developed various yield estimating axioms. A quote from a farmer's journal, "Half-mile rows + (drilled beans – no headlines) + a third up the cab window per round = 53 to 54 bushels per acre. Farmers armed with that kind of empirical accuracy, could do all kinds of long division in his head and make an Official Field Estimate soon after opening it up. The actual accuracy was not very high, of course, but could constantly recalculate, adjusting for assumed moisture, guessing test weight, number of light poles passed, etc., to get some kind of yield guess.

These techniques were applied to sprayer tanks (halfway between the seam and the paint splatter is 300 gallons), fields (the fencepost just east of the township road is almost 20 acres), and bins (if you can't climb in the wheat bin there is at least 3,450 bushels). Each yardstick was obtained by brutal experience—now any dope that can read a digital display can duplicate all.

The farmer of the future will always need to keep his foot in the past.

Precision farming beginnings

In the early 1990's, a farmer could purchases his first yield monitor. At this time precision agriculture was an infant technology. But this infant had some of the signs of eventual greatness, but its full capacities would not be evident for some years. Like all infants it required an investment of time and resources to help it mature. The investment put forward would have some short-term payoff, but the main benefits would be in the future.

The early benefits of site-specific management were difficult to measure. Crop yield changes in side-by-side comparisons of site-specific and whole field technologies might be due to inherent soil differences or microclimate. Simulations of what the field might have produced under another management system was time consuming and often inaccurate.

The early short-term profits were appeared profitable. Companies that sold precision-farming services quickly exploited university studies showing the profitability of this technology. In 1997 Ag Chem Company, Inc., Minnetonka, Minnesota, the foremost supplier of variable rate fertilizer applicators, posted on their web site variable fertilizer successes;

Corn	Minnesota	+$4.45 to +29.15 per acre
Spring Wheat	Montana	+12.00 per acre
Winter Wheat	Washington	+$14.80, +$3.39, +$11.92, and +$10.00 per acre
Corn	Kansas	Was positive at least once for each field tested during a 2 year study
Sugar Beets	MN & ND	+$75, +$48, and +$51.00 per acre
Potatoes	Idaho	+368.17 per acre for "precision ag" over conventional

■ Table 2

In this table adopting variable rate fertilizer was very impressive. But in later studies researchers suggested that variable rate fertilizer failed to cover ALL additional cost in the production of bulk commodities, such as corn, soybeans, and wheat.

Frustration

George Cummins, an extension specialist at Iowa State University, stated his frustration with intensive soil testing techniques. "The Industry promotes grid sampling and point sampling in an effort to apply only the nutrients that are needed. But Mother Nature does not exist in squares and grids. We've used different grids, center point and random sampling, and composite sampling for the past three years. And you'd think we'd see some patterns."

On center point grid sampling – where the sample is pulled from the exactly the point each year – Cummins says there has been absolutely no consistency, even when using the same laboratory for analysis and the same data of sampling.

"We've had center point grid samples with pH readings that vary from 5.5 to 7.4," he says. "It's from the same point. So do you lime? Do you adjust the herbicide rate? Which is it?"

Antonio Mallarino, an associate professor of agronomy at Iowa State, also stated, "We know that soil testing is necessary, but the problem is sampling technique. Certainly the most cost-effective sampling technique is not grid sampling. It's expensive, and in many cases there will be no return."

Having a place

But higher value crops such as sugar beets, and potatoes, can and do document the profitability of intensive soil sampling and variable rate fertilizer in a higher degree. Higher value crops are usually paid by a quality factor, and fertility plays a major role in this quality, thus more of a response to this technology.

Many economists pointed out the necessity of having a site-specific management system, not just varying one or two inputs to consistently pay the cost of site-specific data collection and use. It was also determined that agricultural databases would take time to accumulate. One of the reasons was because of weather variability. Accurate information on site-specific yield potential and problems could require several season of data. For many parts of the country a farmer complete cycle from planting to harvest covered one year.

It was also determined that long run profitability of precision farming technology depended on the development of management systems that link inputs applied with yields harvested on specifics sites. These management systems would be a combination of computerized decision support systems and the accumulated wisdom of experienced managers. Decision support systems require databases. Wisdom comes with long experience. These management systems would be site specific. Generic decision support system would be developed, but their performance on a farmer's farm would be enhanced by data from his farm.

Those farmers who could benefit from precision farming would be determined by how management of precision data is organized. Early adopters realized that they might need to pool data. They realized they could not try every alternative on their farm, but by pooling their data with other farmers, who have different management approaches, would identify the best combination of seed, fertility, tillage, and pest control.

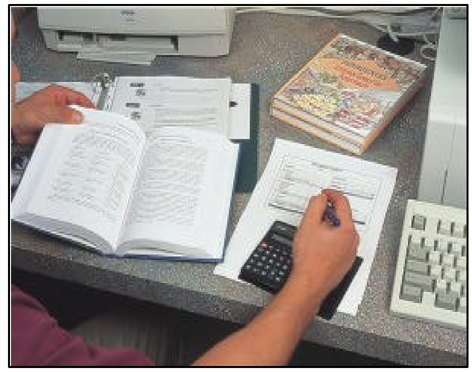
The Farm Manager

So far we have been talking about precision agriculture. But have you noticed that MANAGEMENT has been the dominant focus, and the FARM MANGER, the user of this new technology, is the primary concern.

Farm management is not a series of canny, split second, or "heat of the battle" maneuver skills that are innately personal. Farm management is a learned set of skills that allows the manager to make informed decisions and to implement changes that will move the operation toward its goals. Management success can be measured by the quality and timeliness of decisions, which are likewise affected by the quality and timeliness of information

Quoting Donald M. Fedie, in his book ***How to Farm for Profit***, "It is not an exaggeration to say that the survival of production agriculture as we know it depends entirely on individual producers knowing their exact break-even cost of production on each and every product."

Farm Managers spend their time controlling, organizing, and evaluating, but first they must make a decision. Consistently making good decisions requires time. Experience, information, and knowledge can improve both the speed and soundness of their decisions. Management errors and bad decisions can be a function of time.



Farmers are risk takers. Every decision involves risk. Managers can't eliminate risk, but by employing a combination of risk tools and information the uncertainty can be less severe. It was and will be more than just the traditional tools of hedging, options, and insurance. In the future the farmers were also concerned about contract evaluation and negotiation techniques as contracts become more prevalent. With more farms having more employees, personnel selection and management becomes important not just for production management but also for risk management. The wrong employee or an improperly trained employee can quickly change the potential outcome. Job descriptions, selection tests, training, evaluation, and incentive packages will become important tools to the farm manager of the future.

Another set of tools for the future is that set used for controlling the process to better ensure that the actual process will accomplish the job as planned and to be ready to take actions to correct a situation or to change plans in response to changes in the situation a farmer faces. Strategic management itself is seen as a risk management tool.

Implementing Farm Management and adopting Precision Agriculture, according to Dr. Kent Olson, University of Minnesota Department of Applied Economics;

> "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."

THE VALUE OF INFORMATION

Precision agriculture, when adopted widely, will enhance the viability of U.S. economy by adding a fundamentally new component of value to agriculture's traditional assets of land, labor, and capital. The new source of value is the enhanced capability to learn from the data and experiences explicitly captured within precision agriculture operations. Production agriculture could experience a change similar to that in several other sectors of the economy over the past decade where more effective application of information technology led to the realization that information, and the ability to learn from operations, is an important economic asset.

Issues of intellectual property, data ownership, and data privacy rights are in the forefront of most farmers. Farmers feel the information collected and paid for by themselves is their data, their "trade secrets". It is perceived sharing this data with other farmers or industry will only be used against them in regularity means. But *Grant Mangold, Senior Technology Editor, Successful Farming, and Editor, @g/INNOVATOR* and others have long maintained the real issue has never been "ownership" but "**access**" and "**control**" of data. (It's not who "owns" data, it's who has access to it!.)

With recent renewed discussion of data access and control and "ownership" issues in agriculture, producers need to watch for contractual arrangements regarding collection and use of on-farm data, read the fine print, and aim to use the system to their benefit (add value to your operation).

Agriculture Research- A New Role

This section is a quote from the National Research Council (NRC, 1997)

Historically, the productivity of U.S. agriculture has been fueled by a research and educational system that was largely funded by the public sector and whose effectiveness is envied around the world. In this unique partnership, research problems and findings were communicated through the Cooperative Extension Service. The U.S. Department of Agriculture (USDA) and land grant university researchers conducted the scientific analyses necessary for continual enhancement of production agriculture's efficiency. New knowledge was created in experimental plots and extrapolated to fit actual farm situations.

Precision agriculture is changing the way in which agricultural research can be accomplished. The generation of massive amounts of data on farms will enable dynamic experimentation that could supersede the use of traditional controlled experimental plots. Information technologies can produce quantitative data that will complement qualitative whole-farm case studies. On-farm research will reflect actual farming practices. Further, the agricultural system may need to evolve so that innovation and learning can exploit both traditional research plot experiments and information captured from actual field operations. Farmers engaged in precision agriculture will likely be transformed from research clients into research partners.

Precision agriculture requires new approaches to research that are designed explicitly to improve understanding of the complex interactions between multiple factors affecting crop growth and farm decision-making. USDA and land grant universities should give increased priority to such new approaches by reallocating personnel and budgets.

Understanding the complex interactions among the multiple factors affecting crop growth is the foundation of any attempt to improve management systems. Incorporating information about variability in soils, moisture, nutrients, and pest populations into decision-making requires an understanding of crop growth in an environmental context. Traditional plant and soil science research has not been designed to provide this kind of information, however. The current paradigm is that of the controlled experiment, in which one or a few factors are varied while all others are held constant. Such an experimental design corresponds poorly to a real farm context, in which multiple factors vary simultaneously. Such experiments provide little information about how responses to variations in any one factor change as other conditions change. Furthermore, they are frequently designed to yield qualitative results or quantitative estimates of responses to changes in inputs or other variables over a range so limited as to preclude estimation of responses to the range of conditions found in production fields. As a result, standard research results are frequently of little value in designing spatial models intended for improved decision-making.

Precision agriculture will necessitate a systems approach to experimental research. In this regard, precision agriculture is similar to the application of systems principles in sustainable agriculture and ecologically based pest management strategies. What makes precision agriculture different is the capability to capture data on the production practices actually applied in fields and on the results achieved. Moreover, systems principles are needed to improve farm decision-making, not for themselves alone. Research approaches from ecology and economics, in which multiple factors vary simultaneously and statistical methods are used to identify the effects of variations in individual variables, are likely to be more productive than traditional approaches. Crop science research for precision agriculture should be designed explicitly to produce results that can be used in economic or statistical decision models by decision makers. This research will also need to be interdisciplinary, drawing on expertise in a range of subject areas such as agronomy, plant science, genetics, soil science, entomology, meteorology, weed science, plant pathology, ecology, and economics.

The potential of precision agriculture is limited by the lack of appropriate measurement and analysis techniques for agronomically important factors. Public sector support is needed for the advancement of data acquisition and analysis methods, including sensing technologies, sampling methods, data base systems, and geo-spatial methods.

A basic premise of precision agriculture is that more and better information can reduce the uncertainty producers' face in decision-making and the unmeasured variability in agronomic conditions. Measurement can reduce the uncertainty of decision making without changing the biological variability that occurs in crop production. While the use of information is not new to agriculture, the potential exists for a vast increase in the timeliness and amount of information if additional means of data collection and analysis become available. Only a few commercial sensors are available today. Efforts continue by both private companies and the public sector to develop real-time sensors for additional agricultural indexes. Current sampling and analytical techniques are not designed for managing small units or for in-field decision making. For example, nutrient assays that require soil sampling and physical/chemical analyses are slow and costly. Current mapping techniques are limited by a lack of understanding of the geo-statistics necessary for displaying spatial variability of crops and soils.

New information technologies will be required to make the more detailed and timely decisions necessary for precision agriculture. Introduction of new sensing techniques will enable the collection of an unprecedented number of soil, crop, pest, and weather observations. Maps created from the data can be used during field operations to make more precise and timely application of inputs. Crop production and monitoring will be improved with development of accurate and cost-effective data acquisition and analytical techniques.

Involvement of both public and private sectors is needed to undertake fundamental research, develop field applications, evaluate the utility of sensing techniques, and—more importantly—answer questions about what information to acquire and at what frequency (i.e., which variables warrant investment in information acquisition and at what levels).

Scientific expertise in university and federal laboratories should be focused on determining biological, physical, and chemical principles that may result in improved or expanded sensing techniques. Agencies should recognize the ongoing contributions of industry to precision agriculture sensing and analytical techniques and concentrate their efforts on areas for which there is little incentive for the private sector to invest. Technology transfer mechanisms should be used to promote movement of practical sensing techniques into the marketplace. Collaborative efforts among researchers in the public and private sectors should be focused on sensing techniques that hold potential for accuracy, high spatial resolution, and inexpensive operation.

Multidisciplinary research will be needed to match measurement methods and analytical techniques with crop production questions of interest—to effectively understand and use information about the true variability of measurable parameters within farm fields. Database management and image processing methods are needed to extract useful information from very large data sets. Geo-statistical methods must be advanced both to more effectively sample and to more accurately interpolate sparse data subject to instrument and sampling errors. Spatial analysis methods and spatially explicit components in crop models should be evaluated and calibrated under field conditions, and incorporated into GIS to facilitate accurate analysis and inference from collected precision agriculture data.

In the twenty-first century, agricultural professionals using information technologies will play an increasingly important role in crop production and natural resource management It is imperative that educational institutions modify their curricula and teaching methods to educate and train students and professionals in the interdisciplinary approaches underlying precision agriculture.

Adequately trained professionals will be required to form the bridge between precision agriculture and science and technology. New and emerging technologies such as GIS, the global positioning system, and remote sensing and weather station data will be used in crop models and decision support systems as aids in the farm manager's decision-making process. A broad view of training is needed to ensure the beneficial use of precision agriculture:

- To be successful, prospective employees will need to have the disciplinary depth and analytic skills for understanding spatially variable data. This should be provided by various educational institutions, including the land grant universities and technical colleges.

- Existing professional advisers, including independent consultants, will need continuing education and remote-site learning in precision agriculture technologies because they will be called on to help interpret information for managers who make decisions at the farm level. These professionals may already have valuable field experience that will be enhanced with training on a systems approach to farm management. Technology providers are filling some training gaps. Additional support is needed by state extension personnel and professional societies.

- The professional societies associated with agriculture, biology, earth sciences, and environmental sciences could provide guidance in identifying necessary course work for new professionals and additional training for existing personnel.

Early Adoption Strategies

It was determined that in the beginning, the technology of precision agriculture was rapidly changing. The adoption strategy should be based on finding the least cost way to build site-specific management capacity and databases. Industry realized that agriculture was becoming a knowledge-based industry where the farmer and the farmer's employee's knowledge was a key factor in profitability.

It was realized as early as 1996, that some aspects of precision farming would become standard practice for North American agriculture. But early adopters did not know which aspects would provide the most practical and profitable. They realized the most durable investment that farmers and agribusiness could make was in the development of management skill and databases. Hardware and software would surely change, but site-specific databases and the capacity to use precision management tools profitability would provide a long run competitive advantage.

Farmers should closely monitor the emerging concepts, learning and adapting when appropriate. Avoid complex, expensive purchases before the equipment has been adequately evaluated through research and experience. Determine which components to apply and manage yourself and which services will best be provided by agri-business companies or consultants. According to Pioneer Hi-Breed article "*Precision farming Offers Opportunities and C*hallenges", farmers should do the following;

1. Learn as much as possible about the technology. Be objective as you read magazines, attend meetings, and visit with input suppliers and other farmers who have already purchased components of site-specific management.
2. Gain competence in the use of computers if you want to process the data yourself, or align with someone with those capabilities.
3. Develop a thorough field record-keeping system. These records are needed to utilize this technology.
4. Begin collecting and storing yield information generated by a combine yield monitor. The technology is available today at a reasonable cost, and assessing variation in yield will likely be the key to the next steps in developing site-specific management. It will likely require at lease 3 years of yield data to understand field variability well enough to start managing the variability.
5. Form learning partnerships and alliances with others with knowledge in site-specific management. These could include other farmers, those in agri-business, crop consultants, university staff, etc.

The Tools

Many of the technologies at the core of precision agriculture today—satellites, sensors, and geographic information systems (GIS)—are unusual for agriculture in that they were developed outside the traditional agricultural research, development, and dissemination (RD&D) system and were imported from industries not traditionally associated with agriculture. It is anticipated that investments in development and diffusion of precision agriculture by the private sector will continue at a rapid pace. Finding the appropriate role for traditional agricultural R&D institutions vis-à-vis these technologies has thus been a challenge.

Yield monitoring. Instantaneous yield monitors are currently available from several manufacturers for all recent models of combines. They provide a crop yield by time or distance (e.g. every second or every few metres). They also track other data such as distance and bushels per load, number of loads and fields.

Yield mapping. GPS receivers coupled with yield monitors provide spatial coordinates for the yield monitor data. This can be made into yield maps of each field.

Weed mapping. A farmer can map weeds while combining, seeding, spraying or field scouting by using a keypad or buttons hooked up to a GPS receiver and datalogger. These occurrences can then be mapped out on a computer and compared to yield maps, fertilizer maps and spray maps.

Variable rate fertilizer. Variable rate controllers are available for granular, liquid and gaseous fertilizer materials. Variable rates can either be manually controlled by the driver or automatically controlled by an on board computer with an electronic prescription map.

Variable spraying. By knowing weed locations from weed mapping spot control can be implemented. Controllers are available to electronically turn booms on and off, and alter the amount (and blend) of herbicide applied.

Topography and boundaries. Using high precision DGPS a very accurate topographic map can be made of any field. This is useful when interpreting yield maps and weed maps as well as planning for grassed waterways and field divisions. Field boundaries, roads, yards, tree stands and wetlands can all be accurately mapped to aid in farm planning.

Salinity mapping. GPS can be coupled to a salinity meter sled which is towed behind an ATV (or pickup) across fields affected by salinity. Salinity mapping is valuable in interpreting yield maps and weed maps as well as tracking the change in salinity over time.

Guidance systems. Several manufacturers are currently producing guidance systems using high precision DGPS that can accurately position a moving vehicle within a foot or less. These guidance systems may replace conventional equipment markers for spraying or seeding and may be a valuable field scouting tool.

Records and analyses. Precision farming may produce an explosion in the amount of records available for farm management. Electronic sensors can collect a lot of data in a short period of time. Lots of disk space is needed to store all the data as well as the map graphics resulting from the data. Electronic controllers can also be designed to provide signals that are recorded electronically. It may be useful to record the fertilizer rates actually put down by the application equipment, not just what should have been put down according to a prescription map. A lot of new data is generated every year (yields, weeds, etc). Farmers will want to keep track of the yearly data to study trends in fertility, yields, salinity and numerous other parameters. This means a large database is needed with the capability to archive, and retrieve, data for future analyses.

But according to Dale McDonald’s article in Farm Industry News, July / August 2000, stated; *When precision-farming technologies first entered the marketplace, the allure of sure solutions, followed by certain profit, seemed irresistible. After all, the concept just made so much sense.*

But the passage of time has not rendered a shopping list of technologies with enumerated, quantifiable, short-term profit margins. In fact, researchers continue to generate far more questions than answers – in part simply because the technology is still so new. Simply stated, farmers are very frustrated this technology.

Producers and practitioners have discussed the issue of "data ownership" for several years during the growth of the precision agriculture industry. But what is a "fair" use of your data? Attendees of the conference "**Information Privacy, Confidentiality, and the Right to Know: A Growing Challenge for Workers in Agriculture and Natural Resource Management**" recently heard from privacy and information technology consultant Robert Gellman of Washington D.C. He presented eight principles of "fair information practices" (compiled from several sources) and discussed implications for agricultural databases--and points out that neither data "ownership" nor privacy nor confidentiality adequately describe the issue. (Excerpts below & *complete discussion in @gInnovator*

The agricultural production and marketing system does not have a tradition of understanding and measuring the value of information from operations or the systems that create that value. The experiences of the agricultural sector do not prepare it well for understanding the implications of these changes, even though they could affect research, public sector involvement, and the achievement of economic and environmental gains.

> *Precision agriculture will require clarification of intellectual property, data ownership, and data privacy rights. The extension service should play a leadership role in providing education on existing law pertaining to these issues.*

Precision agriculture will involve, even require, the acquisition and processing of data by a variety of off-the-farm vendors, including crop consultants; farm cooperatives; seed, fertilizer, chemical, and equipment dealers; aerial and satellite remote sensing companies, and software systems providers. Information technology will generate valuable data not only for the producer but for others in agricultural production and marketing. Protection of a producer's data and its availability to others will influence the effectiveness of precision agriculture.

Intellectual property rights and data privacy protections are evolving areas of judicial and legislative activity. Existing legal precedents and contract forms for protecting a producer's data will need to be adapted for precision agriculture. Producer and industry associations have been developing legal templates and forms for producers to use in asserting ownership over precision agriculture data. It will be important to find a balance between protecting individual privacy and securing benefits to multiple users. Leadership by public agencies, such as the extension service, will be needed to develop legal instruments and language to clarify rights and responsibilities of data use and dissemination to producers, crop consultants, and others involved in the data stream.

> *Data collected for use at the sub-field and field level have additional value for research, testing, evaluation, and marketing when assembled into regional databases. Mechanisms are needed to create and use this value, 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.*

The collection and analysis of geo-referenced data from individual farm fields provides an unprecedented opportunity for gaining new insights into the functioning of agricultural systems. Such data sets can provide competitive advantage for private companies and be an invaluable resource for producers and public sector researchers. However, individual farmers may not readily agree to freely contribute their farm's data to a larger pool of data. Commercial companies may not readily release or share data sets they have assembled with universities or the USDA, even though the data might benefit and facilitate research across broader areas. Public agencies, such as the extension service, will be needed to provide leadership in this process by promoting models and templates for data sharing, providing examples of the benefits of sharing and aggregating data, and providing protection for data privacy rights.

One can easily visualize significant benefits from compiling and analyzing data sets generated from precision agriculture. However, care must be taken to ensure the completeness of such data sets so that they will be sufficient to address present-day problems and questions that have yet to be formulated. Because some of these data sources serve more than agricultural purposes (weather, geographic information, and global positioning data), they have their own set of standards. Other data structures (variable-rate technologies, on-the-go sensors, and yield monitors) will be totally focused on agricultural applications and will need to be interfaced with nonagricultural sources. To facilitate this process, standardized formats for data collection, storage, and transfer must be identified. The importance of metadata data standards that define measurement conditions and quality control increases as data from sources outside the farm are used in decision making. Because of the breadth and depth of such data sets, a consortium of public and private sector scientists and practitioners continues to play an invaluable role in formulating, evaluating, and communicating standards.

> "Precision farming is focused on input management way too much," said Todd Peterson, technology manager at Pioneer Hi-Bred International. "The ultimate value of the technology is going to be a combination of process optimization on the farm, and documentation for end users off the farm. Improving the production process is only the beginning. Real value also will come from the things like proving environmental compliance, documenting compliance with quality-based production standards, and offering trace-ability and track-ability to those who purchase the farmer's products."