Adopting Precision Agriculture:

A Decision Making Process

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Introduction

The terms precision agriculture, site specific farming, prescription farming, and others are frequently appearing in agricultural literature in recent times. In this report "precision agriculture" will be used as a broad term to cover all of the above. Precision agriculture is the collection of information and application of various practices to specific sites of varying size. The purpose of adopting precision agriculture is to increase farm income by a combination of increasing yields and reducing the use of variable production inputs, or in short, increasing productive and economic efficiency. Tools of precision agriculture include global positioning systems (GPS), geographic information systems (GIS), yield monitors, computers, field maps, and variable rate applicators. Variable rate applications are most commonly used in seeding, fertilizing, and pesticide applications.

Whether or not one plans to adopt precision agriculture in the future, learning about what it has to offer may be time well spent as there may be some aspect of this technology that would benefit farm efficiency. It is a technology which is likely to be widely used in the future as more is learned about it. Even so, one should take the time to learn about the costs and benefits before getting heavily involved. Some farmers have adopted precision agriculture and have been very pleased with the results. Others have tried it and concluded that income did not increase enough to cover the extra expense. Some are convinced that it has good potential but that yields did not increase enough when prices of commodities are low to make it worthwhile. Some say that the potential for success with precision agriculture is greatest with high value crops such as potatoes or sugarbeets. In any case it seems to be an individual farm decision as conditions are different for each farm.

This report will discuss the various kinds of equipment available and their applications, benefits and costs associated with precision agriculture, and some examples of precision agriculture adopters. As this technology uses many new terms, a glossary of these terms is included at the end of this report.

Information and Management Decisions

Historically the trend in U.S. farming has been increasing farm size and decreasing numbers as technology has allowed one farmer and his or her family to farm more and more acres. Larger farms, more technology, and greater financial demands have increased the need for farm operators and managers to have access to more and better information on which to base decisions.

Precision agriculture provides a means of collecting information about specific areas of a farm or field and ~~the~~ then addresses the needs of those specific sites to improve production or reduce input use. This information, along with previous experience and knowledge of the operator, can lead to improved decisions and possibly greater profitability.

The objectives of this report are:

1) To describe precision agriculture and discuss how it may be helpful to farm operators.
2) To provide guidelines to farm operators who may be considering adopting some aspect of precision agriculture on their farms.

Literature Review

Lowenberg-DeBoer and Swinton (1995) suggest that there are three main forces bringing about the adoption of precision agriculture.

1) Technologies like GPS and high tech electronics make identifying field locations and collecting data simpler and less expensive.
2) Competition is forcing farmers to improve efficiency and quality, agribusinesses to offer new services, and former defense contractors to seek new markets for their high tech knowledge and products.
3) Environmental concerns and public policies are leaning on farmers to show that they are good stewards of the land.

How quickly precision agriculture is adopted depends on its profitability. Farmers can not afford to jump into this new technology without knowing that there will be some kind of benefit. Synder et.al. (1996) concluded from their study on variable nitrogen applications that the economic benefits depend on the farmer being able to identify those places in a field where precision potential exists. In other words, if a grower can simply identify where in his field the added costs of precision will pay off with increased yields, then there exists the possibility of an economic benefit. The problem however, is that knowing where those locations are or being able to find them may be incredibly difficult if not impossible. Results from interviews with Michigan growers and agribusiness people showed that many farmers considered information and better data for making decisions to be a significant enough benefit to adopt precision technologies (Swinton and Ahmad, 1996).

Almost all of the literature currently available on the economics of precision agriculture agrees that its profitability is difficult to measure (Lowenberg-DeBoer and Boehlje, 1996) and that one can not make a blanket statement which will apply to all situations (Lowenberg-DeBoer and Swinton, 1995). Lowenberg-DeBoer and Swinton (1995) in a study on the economics of site specific management said that the profitability of precision agriculture is "site specific and should be evaluated on a farm by farm or field by field basis." Many of the current studies that have found precision agriculture not to be profitable have only used one input to cover the entire cost of adopting this new technology. Increasing one's profitability can be done by spreading the costs of collecting data over all of the inputs associated with that crop's production (Lowenberg-DeBoer and Boehlje, 1996).

When it comes to actually adopting these practices, it may be tempting to try too much at once. Although Lowenberg-DeBoer and Boehlje (1996) feel it is more economically beneficial to spread the costs across all inputs, others suggest that beginners take things slowly. Perry Peterson, manager of precision farming for Terra Industries cautions growers about making major changes. "We don't have many 'normal' years…therefore, we need to look at longer-term averages – at least three to five years – before making key revisions" (Brunoehler, 1997). A slow and educated approach will likely get the best results.

Dennis Lindsay, a farmer of 1,400 acres near Masonville, Iowa has said in Successful Farming that the monetary costs will not stop farmers from adopting this technology, however the real cost is time. He says, "information by itself is no good. Figuring out what can be done with it is harder work" (Hays, 1996). He has seen some payoff in the reduction of nitrogen applications in his fields.

Rupert, Idaho grower John Remsberg has used variable rate fertilizing for five years, but isn't sure it is paying for itself at this point in time. He believes that there are still some bugs to work out, but that this technology will stay. Some of the equipment needs to be more compatible with field conditions like dirt and moisture (Daines, 1998). Kansas producer Kent Stones notes that a problem with yield monitoring is the struggle to understand and process the vast amounts of data it has provided him. It has raised more questions than answers and he admits that "my expectations were far higher than what [he] has been able to accomplish thus far" (Lilleboe, 1998).

Another application of this technology, besides being used on one's own land, is in a custom operation. One young, newly graduated university student, Bryce Rupert from the University of Illinois has decided to purchase a yield monitor for custom farming. He wants to help smaller farms get involved with precision farming and would be able to spread the cost of his monitor over more acres. He believes that one needs to invest in the future to stay in business (Mangold, 1996).

Equipment

The precision agriculture components and equipment discussed in this report are representative of what is on the market and not by any means all that is available. This paper does not promote or endorse the use of any particular make or model of equipment. Researchers suggest that farmers thoroughly analyze what will work the best for them and their operation before buying, leasing or using any of the precision options and services available. Some of the components of data collection and precision farming are discussed in this section.

Global Positioning Systems (GPS)

Starting in the 1970's the U.S. military began launching satellites to help them pinpoint specific field locations. These high orbit satellites are able to pinpoint a location by transmitting back to earth longitude, latitude and altitude signals. Receivers on earth take the signal information from up to four satellites simultaneously, calculate how much time it took the signals to get here, and then approximate the location (Trimble, 1998).

For security purposes, the military has scrambled these signals, causing them to be off by up to 400 feet. This is not accurate enough for farming applications, so another stationary signal is needed to adjust for proper accuracy. Currently that accuracy is with in a few feet and continues to improve.

The process of correcting the GPS signal is called differential correction, or differential GPS (DGPS). Differential correction measures the errors built into the GPS system. A stationary or fixed receiver takes the signals and measures how far off it is from its known or fixed location. The 'corrected' signal is then sent to the machine in the field.

Several differential correction options are available such as, the U.S. Coast Guard radiobeacons, low orbit geostationary satellites, FM sideband, and an individually owned stationary receiver (tower).

1) Coast Guard radiobeacon signals are free, however they are only offered near major inland waterways, like the Columbia River Gorge, coastal areas and the Great Lakes. The radiobeacon signal is not practical for farmers too far away to benefit from this free service because it only has a range of 60-200 miles. Extreme weather and topography can also affect the signal. Farmers able to use this service need to specially equip their receiver to pick up the Coast Guard signal.
2) Low orbit geostationary satellites cover the continental United States and parts of Canada. Their accuracy has historically been within three meters. Individual companies usually pay to put them into orbit. Topography and weather are not problems. It has parallel swath guidance capabilities that are accurate to within a foot. Besides needing to have the proper GPS and DGPS receivers there is a yearly subscription fee between $250 - $1,000.
3) The signal sent over a sideband of local FM radio stations is broadcast from companies that have set up individual base stations. This allows a farmer to have the level of accuracy they require based on how much of a monthly fee they pay. However, it does make them vulnerable to coverage limitations (only a 20-40 mile radius) and the possible lack of reliability due to topography problems.
4) Having a base station on one's own farm can be very expensive, although prices are declining. The advantage of having a privately owned station means that a farmer will have access to accurate

corrections all of the time. This method requires the owner to survey before creating any data to make sure the location is accurate. Otherwise, if a soil sampler comes in and uses another receiver, the grower's data would not be compatible. (Trimble, 1998)

The number of channels a GPS receiver has helps determine its quality. The roving field receiver gets location information from four GPS satellites, and the DGPS signal from a stationary point. It then calculates its location in the field and sends that information to an onboard computer, storing the data for later map creations to be used for making decisions. Best results are achieved when the receiver is mounted on the highest point of the piece of machinery. The receiver also has to be centered for consistent and accurate data collection.

Pointon (1997-1998) advises farmers to take into account the type of applications, how important accuracy and reliability are to them, and other equipment with which it would be used. The difficult part is to get the performance needed for the least cost. In researching what receiver will work best, a farmer needs to find out exactly what kind of accuracy the equipment offers. Farmers also need to check the versatility and compatibility of the receiver with other equipment.

Yield Monitors

One of the most common and simplest ways to start with precision agriculture is to add a yield monitor to a combine or other harvesting equipment. A field that appears uniform to the human eye can be found to have serious variability. Yield monitors are not only a way of finding where those variations are occurring, but can also provide data on the effectiveness of fertilizer and pesticide applications.

The data needed to find the most accurate yield measurement are ground speed, swath width, moisture content of the product, and material weight. Current yield monitors on the market are designed to measure the amount of material that flows through the combine clean grain system and also measures the average moisture content. Ground speed data can be supplied by the DGPS receiver or ground speed sensing radar. Ess and Parson (1995) recommend not using a speedometer that estimates speed based on transmission shaft speed due to slippage and possible errors. Swath width, not header width, is entered into the onboard computer by the operator.

Most of the current users of yield monitors are measuring yield variability. This variability is related to soil type, drainage, weeds and other factors. Yield monitoring can also help with testing different hybrids and varieties (Brunoehler, 1997). A yield monitor can give farmers a good 'on-the-go' or 'real-time' estimate of what is happening as they harvest their fields. When first integrating a yield monitor into an operation extra time should be allocated to use and adjust the equipment. In order to get good quality data the monitor will need to be recalibrated for each field. Also the operator will need to make sure the monitor is working all of the time. Missed data entries can cause problems later when trying to interpret yields.

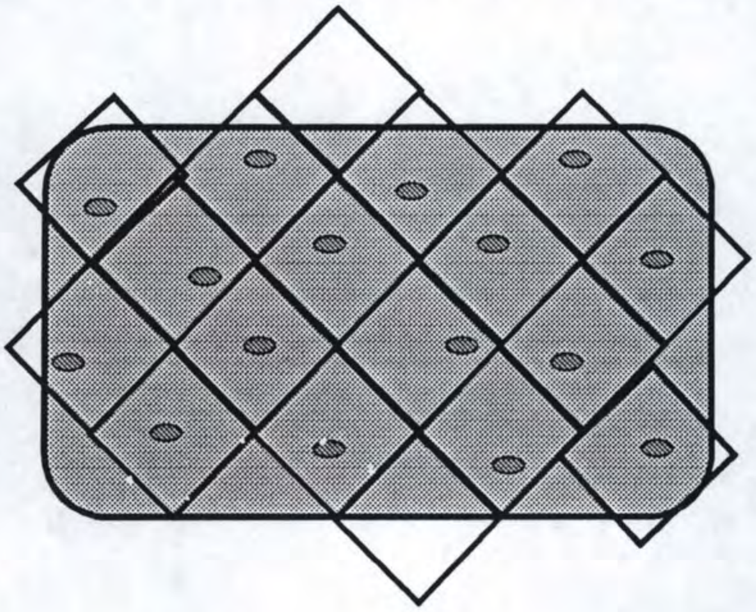
Yield monitors are presently available for wheat, soybeans, corn, barley, other small grains, potatoes, sugarbeets and other major crops. Monitors for tomatoes, cotton, peanuts and other crops will be on the market soon.

Soil Sampling

Soil scientists have known for years that fields vary in soil type, texture, nutrient levels and capacities. Before, farmers were encouraged to farm by soil classifications. As farming became more advanced and mechanized it was no longer economical to farm in that manner. Fields became aggregated and "whole field" applications were the most economical option. With the introduction of GPS and precision agriculture farmers once again are able to farm by soil characteristics. The information provided by soil sampling has even more importance now in a grower's decision making process because of this ability to return to specific field locations over and over again.

There are many patterns used for soil sampling. The most common is the basic square or honeycomb grid laid over a field (see Figure 3). Sampling can be a large expense, so care must be taken to choose an appropriate grid size. While small grids are necessary for more accurate results, sampling costs increase as grid size is reduced. For example, sampling on a four-acre grid versus a one-acre grid will cost much less but will overlook some of the variability that can occur within a field. Some current precision agriculture users suggest that initial sampling should be done on a small, say one-acre grid and then future sample grid size can increase.

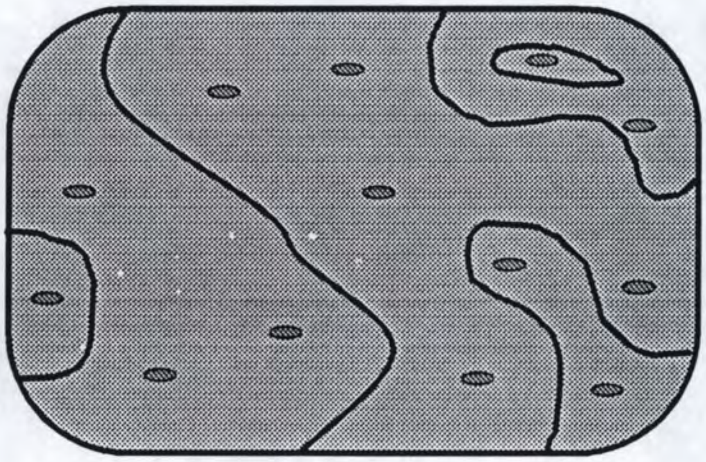
Figure 3: Example of a one-acre square grid laid over a field with marked soil sample sites.



After laying out the grid over a field, sample sites need to be chosen. It is best not to take evenly spaced sample points due to possible biases from previous management techniques such as fertilizer application patterns. Placing the grid at an angle, as in Figure 3, also helps to decrease sampling biases. When actually sampling, scientists suggest collecting eight to ten soil cores for each grid cell in a radius of ten feet from the chosen sample point. U.S. research has found this method to be more accurate than taking random samples from the entire grid cell (Reid, 1996).

In a situation where significant field history is known sampling by small nutrient management areas can be just as effective and less costly. For example a farmer could divide a field up by known fertility patterns, topography or soil type and then choose a given number of samples to take from each management area (see Figure 4).

Figure 4: Example of soil sampling by topography or soil type with marked soil sample sites.



No matter what method a farmer chooses, it is recommended that when taking repeat or yearly soil samples, they be taken at the same time of year. This reduces some of the year-to-year variability due to tillage and weather conditions. Current recommendations on how often to sample range from two to four years depending on the results of initial or previous testing. One also needs to consider the tillage system used to determine the depth of sampling (Morgan and Ess, 1997).

Geographic Information Systems (GIS)

Joe Berry, a geographic information specialist, suggests that when looking for mapping software farmers should look beyond “how pretty and how much.” Mapping software differs not only in price, but also in its ease of use, capabilities and the system requirements to run it. @gInnovator has put together a list of information farmers should find out when researching a program for their operation.

"The first two categories are concerned with software demands on both your computer and your patience in getting started," notes Berry. "The next category investigates how you get data into the system and, just as important, how you keep everything straight. The fourth addresses what the system can do with the data—your return on investment. The last category summarizes relative strengths and weakness."

The five broad categories of information are:

1) System specifications -- Compare general information about the product, including the kind of user for whom the software was developed (i.e. a novice or an advanced computer operator), the product's capabilities, and ease of use (i.e. is it "user friendly"). Also take note of the minimum and recommended hardware specifications (see Table 1).
2) Software installation/support -- Note the installation process and level of support offered by the developers and/or distributors.
3) Data handling -- Consider procedures for importing and exporting data, merging and disaggregation (data manipulation procedures which help the user visualize patterns), data management and archiving (including handling multiple data sets), and entry of other data (crop records, weather data, aerial photos, satellite imagery, etc).
4) Map generation and summary reports – Check out procedures for cleaning up data, generating and customizing map displays, companion maps (such as crop moisture or elevation), creating summary reports, graphs, or tables, and performing data analysis.
5) Overall evaluation – Record relative strengths and weaknesses of a system and assess how it meets your needs.

Table 1: A Range of Possible Computer Systems Specifications.

	Minimum	Recommended
Operating System	Windows 3.1/DOS	Windows '95, Windows CE or NT
CPU Family	80486 microprocessor	Pentium processor
CPU Speed	33 MHz	100-233 MHz
RAM Memory	8 MB	16-32 MB
Hard Drive Disk Storage	80 MB	1.0 GB
PC Card	Type II for data card reader	Type II or III for data card reader
CD-ROM Drive	No	yes
Graphics	i.e. video card type: EGA	i.e. video card type: SVGA
Printer	9x9 BW Dot matrix	color inkjet/laser
Monitor	color VGA	color VGA
Yield Monitors[†]	count and identify the number it directly supports	count and identify the number it directly supports
GPS Receivers[*]	count and identify the number it directly supports	count and identify the number it directly supports
Modem	not necessary unless online with the internet, but be sure to check it's speed	not necessary unless online with the internet, but be sure to check it's speed

† check the software's capability to link yield monitor data and ask vendor for known compatibilities

* check the software's capability to link GPS data and ask vendor for known

Sources: Joe Berry of Berry & Associates for @gInnovator, Cherly Kohls from Crop Production Services in St. Paul Park, MN and John Deere Company.

Farmers need to keep in mind that although they may not be able to use all of the features of a program when they begin, they should leave themselves room to grow. It isn't wise to have to purchase another program in the near future because the initial program can't perform all of the necessary operations the grower now wants. Another suggestion is that for graphic intensive software programs, which the mapping software programs are, the more RAM it has the better.

Another hard lesson to learn with computers is saving and backing up data! Mistakes and problems occur, sometimes at the most inopportune moments, and a farmer can lose years worth of data. Be sure to use some sort of backup method. Backup tapes, extra floppy disks (which can have problems too), re-writeable CD-ROM disks, zip disks and jazz disks are available. Others have also suggested keeping a copy of records off the premises in case of house fires or other accidents.

Remote Sensing and Infrared Photography

Remote sensing and infrared photography are other tools being used by some growers along with precision agriculture for monitoring crop growth. They are high tech geo-referenced images that will provide a background for ownership boundaries, yield and fertility maps, and for soil sampling strategies (Frazier et. al., 1995).

Remote sensing works by satellites measuring the energy reflected or emitted from an object of interest (in this case the crop). Different areas of the field will emit various amounts of energy therefore giving various shades of color or contrast to a map. The lighter areas of a field indicate that some specific attention needs to be given in those areas. The images come in either black and white or color. The color images have a greater resolution resulting in a clearer picture. These satellites cover the entire U.S. and Canada and with one shot a grower gets 37 square miles or 800,000 acres, however they can purchase only the specific township(s) they are interested in.

There are some drawbacks that are hindering the adoption of remote sensing in farming operations. First is the limitation of these satellites due to being in a fixed orbit. Some satellites will pass over an area only once every 16 or 26 days. Unless a remote sensing provider has several satellites, images can only be taken once in a single satellite's cycle around the earth. This isn't an efficient method of data collection for a grower whose crop is changing on a daily basis. They are also limited sometimes by weather conditions, which can reduce the amount of clear resolution on an image. Second is the amount of time it takes for the grower to actually receive the image (this is known as turn around time). Timing is critical in some areas of farming. For example, if a farmer finds an infestation of pests in his field he needs to act immediately in order to keep the spreading of those pests and damage to his crops to a minimum. It many cases it may take as long as two or three weeks to receive remotely sensed pictures and if a farmer has a pest infestation, that is too long. The critical time in which to take action has passed. The last drawback is the economic feasibility. Images from these satellites can vary by type (panchromatic or multispectral), size and the amount of processing the grower wants. The amount of processing affects the turn around time and expense of an image. Panchromatic images vary from $2,800 to $3,950 and multispectral images range in price from $1,950 to $3,150 for the 37 square mile area (Morgan and Ess, 1997).

Infrared photos are similar to remote sensing images but are taken from an airplane. They have the advantage of being taken when a grower wants them and the turn around time is faster. Infrared photos are taken during the growing season to help spot stressed areas. Disease, weeds, insect infestation, nutrient deficiencies, or lack of moisture can cause stress areas that infrared photographs can pick up. For example, a field under pivot irrigation with a circular pattern of stress could very well indicate a lack of water to that area. Maybe a nozzle isn't working properly and the grower couldn't tell from eye level that the field had a stressed area. The ideal infrared photo of healthy plants would be a solid dark red color. When stressed areas occur, they appear as lighter shades of red on the photos. Currently these images produce a higher resolution image than remote sensing and are more cost effective. They are smaller in size and may cost row crop producers around $7/acre for an entire season (Morgan and Ess, 1997).

Variable Rate Technology (VRT)

The ability to vary nutrients, seeding, and pesticides has eliminated the need for historical "whole field" applications. Variable applications of fertilizers and chemicals are available through many dealerships if a farmer is unable to afford the equipment himself. There are two methods of implementing variable rate applications; map-based VRA and sensor-based VRA. For the map-based application a disk with a map created from the farmer's data is inserted into the onboard computer, which then regulates the flow of material(s) while crossing the field. This is considered to be the preferred method, however it requires the use of DGPS equipment to position the machine in the field. After applications are completed a report can be created with some systems that tells the farmer exactly how much material was applied and where it went in the field. Sensor-based applications use real-time sensors to measure soil and crop characteristics (soil organic matter, soil moisture, light reflectance of crops and weeds and soil nutrient level) to determine material distribution in the field (Morgan and Ess, 1997).

Although it is still relatively new and expensive, there is equipment available now that can vary seed populations and even seed varieties as the operator crosses the field based on computer maps developed from yield and soil data. There are also new systems being developed, which allow for the variation of water applications on center pivot irrigation equipment, tillage equipment, and pest management. These are new techniques and research is still being done to improve application.

Farmers also need to take into consideration the accuracy of variable rate applications. Here again, like the yield monitor situation, calibration can play a major role in the amount of extra time spent with this equipment and how accurate the application(s) are. Morgan and Ess (1997) note that this aspect of precision farming requires more management.

Another tool that is combined with other precision agriculture equipment is a parallel swath guidance system. This system is installed in equipment (i.e. a sprayer) to help guide the operator. The idea is to drive in exactly parallel lines across the field resulting in less overlap and fewer skips saving the farmer time and money. A display in the cab has a lightbar that lets the driver know if they are deviating from the projected straight course. It is useful for working in the dark and eliminates the need for foam markers.

Benefits

Farmers are often considered to be price takers, as they participate in a very competitive market. They are, however, profit motivated and attempt to maximize net returns from their farming operations. This may be done by increasing output, improving quality, reducing production costs, or some combination of these. Successful new technology may deal with any of these three factors. It should be noted that new technology, which has not been tested, is associated with an increase in risk until it has been proven to be beneficial.

Precision agriculture consists of several new techniques, which are used singly or in combination. Does precision agriculture pay? Unfortunately there is no concrete yes or no answer to that question because economic benefits will not be the same for all geographic and agricultural regions, farms, or crops due to the variability of soils, climates, costs and availability of services, and management styles (Daberkow, 1997). Gary Wagner of A.W.G. Farms Inc., a grower and six year user of precision agriculture technology in Climax, Minnesota, says that he "can give a dozen examples, where we have increased yields, saved money, understood certain problems, but when a learned activity is done over a period of time how can you put a dollar value on [it]?" He also says that "many agri-industry people are selling this concept as absolute, without error, but it is a lot like farming, it's an art. Most times there are no black and white answers."

Precision agriculture is a new field, therefore the research on benefits and profitability of its adoption is limited. Table 2 gives a summary of possible profitability outcomes from applicable and published studies to date. The studies show a variety of outcomes because of the differences in assumptions made about the cost of sampling and variable rate applications. Studies that found precision agriculture to be profitable had higher net returns when compared to the traditional whole field management (Lowenberg-DeBoer and Swinton, 1995). One common factor Lowenberg-DeBoer and Swinton (1995) found among the profitable outcome studies was that the testing had been done on a high value crop such as potatoes or sugarbeets. They also believed the common attribute of the nonprofitable studies was the involvement of low valued crops.

Precision agriculture also has the potential to benefit the environment. Society is paying more attention now to agricultural inputs and practices. They are becoming more concerned and starting to enact regulations that will affect farming operations. For example, the U.S. Environmental Protection Agency estimates that 50 to 70 percent of the assessed surface waters in the U.S. are adversely affected by nonpoint source agricultural pollution. And, the U.S. per acre fertilizer application doubled between 1965 and 1984 with nitrogen applications increasing even faster (USDA, 1995).

Whole field applications are not only inefficient, but could potentially harm the environment. The excess of both chemical and nutrient inputs from over application can leach into groundwater, potentially causing problems. Precision agriculture offers farmers an option that will make their practices more environmentally neutral and show that they are good stewards of the land.

The relationship between soils, chemical movements in soils and the amount plants uptake is not completely understood by scientists. However, by knowing as many details as possible about field soil characteristics, more precise applications of inputs can be made thereby reducing the amount of runoff and leaching. When paired with GPS and the ability to variably apply inputs, this 'precise' management has the potential to improve the environment.

Table 2: Profitability conclusions from 17 published site-specific management studies.

Study	Crop	Inputs Managed	Duration	Grid cell	Treatment of Sampling and Variable Rate Technology	Site-specific Management Profitable?
Empirical yields			Year	area in acres	Cost ($)	
Anonymous	Sugarbeet	N	2	2.75	Variable and fixed custom rates	Yes
Carr et al., 1991	Wheat, barley	N, P, K	2	n/a	Not included	Mixed
Fiez et al., 1994	Wheat	N	2	plot trials	Not included	Yes, potentially
Hammond, 1993	Potato	P, K	?	0.9	Variable & fixed	Inconclusive (costs only)
Lilleboe, 1996	Sugarbeet	N	1	4.1	Variable & fixed custom rates	Yes, for 70% of 897 fields
Lowenberg-DeBoer et al., 1994	Corn	P, K	1	3.5	Variable & fixed custom rates	No, but might for low-soil test fields
Malzer, 1996	Corn	N	2	strip trials	Breakeven of $8/acre assumed	Yes, in 3/4 of site years
Schnitkey et al., 1997	Corn, soybeans	P, K	1	2.5	Breakeven of $4/acre assumed	Yes, for 15 of 18 fields
Snyder et al., 1997	Corn	N	2	0.75	Variable	Mixed; depends on year and site
Wibawa et al., 1993	Wheat	N, P	3	0.06	Variable & fixed w/ 1-yr amortization	No
Wollenhaupt & Buchholz, 1993	Corn	P, K	?	2.5	Variable & fixed w/ 4-yr amortization	Mixed; depends on yield gain
Wollenhaupt & Wokowski, 1994	Corn	P, K	?	2.1	Variable & fixed w/ 4-yr amortization	Mixed; depends on yield gain
Simulated Yields						
Beuerlein & Schmidt, 1993	Corn, soy	P, K	8	0.25	Variable and sample, no equip	No, but more efficient fertilizer use
Hayes et al., 1994	Corn	N	1	soil survey	Not included	Higher revenue has potential to cover costs
Hertz & Hibbard, 1993	Corn	P, K	24	2.5, 10	Variable & fixed custom rates	No, but close to uniform in profitability
Mahaman, 1993	Corn	P, K	1-4	0.25	Variable & fixed custom rates	No if 1-yr sample amortization; yes if 4-yr amortization
Oriade et al., 1996	Corn, soybean	Herbicides	10	10 subfields	Variable	Mixed; depends on weed patchiness

Source: Lowenberg-DeBoer & Swinton, 1995. pp.385-387.

Costs

Equipment

The largest expense of precision agriculture is the investment of equipment. Many companies currently have equipment on the market, although capabilities and costs vary quite a bit. Table 3 gives a range of prices for some of the kinds of equipment an operator might need to purchase. A farming operation that already has a computer system in place (i.e. for record keeping purposes) will likely spend less money now than an operation starting from the ground up. A farmer with some computer knowledge is also more likely to save some learning time.

When looking at the cost of a service (i.e. soil sampling, variable rate fertilizing) or equipment (i.e. yield monitor, computer software) a grower needs to be looking at a long-term investment. Although one particular model may cost less now, a farmer needs to determine its useful life. That farmer may pay less in the long run if he only has to purchase one rather than two or more pieces of equipment over the next five to ten years. While computer technology can be outdated rather quickly, purchasing 'upgradeable' equipment can save some money. Paying for a \$200 - \$800 upgrade (what most computer upgrades currently cost) is much less expensive than buying another \$5,000 piece of equipment.

As with any purchase, the opportunity cost or interest on an investment should be included in the total cost of the equipment. An opportunity cost is defined as "the income that could be received by employing a resource in its most profitable alternative use" (Kay and Edwards, 1994). For example, if a grower purchases a \$5,000 yield monitor he ties up his money in that investment. If he had invested that money at an 8% annual interest rate (the most profitable alternative) he would have earned \$400 in the first year. That \$400 then is the opportunity cost of purchasing the yield monitor.

Table 3: Costs of Precision Equipment and Services.

Equipment	Price Range	Equipment	Price Range
GPS & DGPS		**Yield Monitors**	$2,800 - $5,000
Coast Guard Radiobeacon			
receiver	$2,500 - $4,000	**Remote Sensing**	
subscription fee	$0	(black and white or color)	
		37 square mile (800,000 acres)	
FM Radio Sideband		panchromatic	$2,800 - $3,950
receiver	$2,800	multispectral	$1,950 - $3,150
subscription fee	$600	individual township	
		minimum order of 7	$395
Satellite		order of 8 -10	$295
receiver	$5,000		
subscription fee	$250 - $1,000	**Infrared Photos**	$7/acre/season
parallel tracking	$15,000		
		Soil Sampling (custom)	per acre
Your Own Base Station Tower		sampling	$2.00
receiver	$2,500 - $3,500	mapping	$2.00
subscription fee	$0	gridding	$2.00
installation	$30,000	topography maps	$2.00
		yield data	$1.00
Variable Rate Technology		scouting	$3.00
spray controllers	$1,700 - $4,000	data management	$6.00
parallel swath guidance (w/DGPS)	$5,000 - $15,000	complete soil test	$15.00
variable rate seeder	$95,000	package deal	
		irrigated acreage	$22 - $28
Computer System (GIS)		dryland	$10 - $12
office computer	$4,000 - $5,000		
accessories (i.e. printer, mouse)	$2,000		
software			
beginning	$600 - $3,500		
advanced	$3,500 - $8,000		
field computer (laptop)	$3,000 - $5,000		

Sources: Cheryl Kohls from Crop Production Services in St. Paul Park, MN (1997 price data), Holmberg with Successful Farming, October 1996 Issue, Kent Madison Farms, Precision-Farming Guide for Agriculturists, and Richard Johnson from Northwest Precision Ag, Inc. in Blackfoot, ID (1997 price list)

Time and Labor Management

The introduction of any new technology requires more skilled labor and training. Other important costs besides the equipment are time and labor. Most of the current adopters have noted that they spend considerably more time in preparing for different farm operations (such as spraying and harvesting) yet about the same amount of time actually performing those operations. They have to sit down ahead of time and develop a map for variable rate applications. When harvesting they have to calibrate the yield monitor for each field and continue watching the monitor to make sure it is working properly. Because decisions are only as good as the data they're based on, accumulation of accurate data is highly important. That means training hired help to be as conscientious and precise as needed to get the necessary data. They have to learn how to work with the new equipment and how to deal with problems that arise. The farm manager needs to determine what his time is worth and how much of that time he can afford to spend on learning a new skill. For example, if a hired hand has to spend an eight hour day learning to operate the new equipment and he is paid $7.00/hour, then that $56.00 investment of time should be included in the cost of using that equipment, in addition to extra time spent by a trainer or supervisor.

Partial Budget Examples

There are many case scenarios that could apply to an individual farm. This paper will look at two simple scenarios to illustrate partial budgeting. Partial budgets are used to weigh the benefits of increased revenues and decreased costs against the possibility of decreased revenues and increased costs. The partial budgets in this paper are figured on a cost per acre basis. The first partial budget example is of a situation where precision agriculture has increased product quality but has not decreased any of the input costs (see Table 4). Both budgets are designed to show how costs and returns for an operation could be determined. A grower could then substitute his or her own actual costs and returns to see whether or not investing in precision agriculture would be a profitable decision.

Table 4:

Partial Budget for 800 acres of potatoes

Additional Costs	$/acre	Additional Revenue	$/acre
Yield Monitor w/dGPS	$ 2.50	Increased Quality	
Soil Sampling	$ 14.00	(330 sacks x $0.22/sack)	$ 72.60
Variable Fertilizer Apps	$ 8.00		
Variable Chemical Apps	$ 8.00		
GIS	$ 0.56		
Labor	$ 3.60		
Subtotal	$ 36.66	Subtotal	$ 72.60

Reduced Revenue	$/acre	Reduced Costs	$/acre
	$ 0.00	Fertilizer	$ 0.00
		Water	$ 0.00
		Seed	$ 0.00
		Pesticides	$ 0.00
		Fuel	$ 0.00
		Machinery	$ 0.00
Subtotal	$ 0.00	Subtotal	$ 0.00
Total Costs	$ 36.66	Total Revenue	$ 72.60
		Net Change in Profit/acre	**$ 35.94**
		Increased Net Returns for total 800 acres	**$ 28,750**

*Footnote.

These costs assume that the farm already has an adequate computer for precision agriculture applications. If it does not, then "additional costs" would be increased by the appropriate proportion of annual operating and ownership costs of a computer which are allocated to precision agriculture.

The cost of the yield monitor was assumed to be $8,000 and included the cost of the dGPS signal. It was depreciated for an estimated four year useful life with no salvage value, bringing the yearly cost to $2,000. It was then divided by the 800 acres, which came to $2.50 per acre. A complete soil sample test was $14/acre. In this case scenario the soil tests were repeated each year. If the soil tests were made at 3 to 5 year intervals the annual cost would be reduced. The software program cost $1,800, which assuming it is used solely for the 800 acres of potatoes and is applicable for four years, would cost $450. Spreading the cost over 800 acres came to $0.56 an acre per year. Potatoes are a labor-intensive crop and in this scenario the extra labor spent on learning, planning and implementing precision agriculture added a half an hour per acre over the entire season (planting to harvest). With labor valued at $7.20/hour (Idaho Extension Bulletin EBB4-Pol-97), the labor cost increase came to $3.60/acre. The variable application costs included both fertilizer and chemicals. The charge per acre will vary, depending on how many acres the dealer is treating. The more acres covered the lower the application cost per acre. In this case they charged an extra $8.00 an acre for both fertilizer and chemicals. In this situation the higher quality product (more uniform in size and less bruising) received an increase of $0.22 per sack from the packing shed. With an average of

330 sacks per acre (average for Southeastern Idaho, Idaho Extension Bulletin EBB4-Pol-97) the additional revenue came to $72.60 per acre. Overall in this scenario the grower would have seen a profit of $35.94 per acre and $28,750 for the entire 800 acres.

The second example is of a situation where there has been both a decrease in costs and an increase in revenues (see Table 5).

Table 5:

Partial Budget for 800 acres of spring wheat

Additional Costs	**$/acre**	**Additional Revenue**	**$/acre**
GPS and dGPS	$ 0.00	Increased Yields	
Yield Monitor	$ 1.41	(6 bu x $3.50/bu)	$ 21.00
Soil Sampling	$ 6.00		
Variable Fertilizer Apps	$ 8.00		
Mapping Recommendations	$ 2.00		
Royalty Fee	$ 3.00		
GIS	$ 0.31		
Labor	$ 0.36		
Harvest Costs	$ 2.40		
Subtotal	$ 23.48	Subtotal	$ 21.00
Reduced Revenue	**$/acre**	**Reduced Costs**	**$/acre**
	$ 0.00	Fertilizer	$ 3.55
		Water	$ 0.00
		Seed	$ 0.00
		Pesticides	$ 1.15
		Fuel	$ 0.00
		Machinery	$ 0.00
Subtotal	$ 0.00	Subtotal	$ 4.70
Total Costs	$ 23.48	Total Revenue	$ 25.70
		Net Change in Profit	**$ 2.22**
		Increased Net Returns for total 800 acres	**$ 1,778**

*See Footnote at the end of Table 4.

The cost of the yield monitor was assumed to be $4,500 and had a free dGPS signal. It was depreciated for an estimated four year useful life with no salvage value, bringing the yearly cost to $1,125. The annual cost was then divided by the 800 acres, which gave a yearly cost per acre of $1.41. The complete custom soil sample testing expenses totaled $12/acre, however the tests were only conducted every other year making the yearly expense only $6/acre. The maps created from the soil test results were used to make recommendations on where to add soil amendments cost $2/acre and then the actual variable rate fertilizing application came to $8/acre. In this situation there was also a royalty fee of $3/acre charged by the company doing the variable rate work. The software (GIS) package was purchased for $1,000, which assuming it is used solely for the 800 acres of spring wheat and is applicable for four years, would cost $250 year. Spreading that cost over the 800 acres came to $.31/acre. Wheat is not very labor intensive so the amount of time spent in planning and applying precision technology was less than in the potato budget. Over the entire season 40 hours of labor were added for time spent calibrating and operating this new equipment on the 800 acres of wheat. At $7.20/hour (Idaho Extension Bulletin EBB2-SW-97) this came to a $0.36/acre increase in labor costs. This is does not include time possibly spent by the farm manager learning about precision agriculture and how to install the equipment. For the increased amount of product, harvest and hauling expenses would also increase. At $0.20/bu the additional harvesting costs came to $1.20/acre and the hauling costs were also an additional $1.20/acre for a total of $2.40/acre increase in harvesting costs. In this situation there was no premium for a higher quality product. However, there was an assumed increase in production of 6 bushels per acre. The increase in production could also be attributed to weather and other possible circumstances, not just the application of precision farming techniques. This increase, valued at a $3.50/bu price, lead to a revenue increase of $21.00 per acre. The fertilizer expense dropped by 5 pounds an acre for Nitrogen, Phosphorus and Sulfur at a cost of $0.34, $0.25 and $0.12 per pound respectively. The fertilizer cost decrease totaled $3.55 per acre. Pesticide use also dropped by a total of $1.15 per acre. Overall in this scenario the grower would have seen a profit of $2.22 per acre and $1,778 for the entire 800 acres.

Another possible scenario would be if a farmer chose to adopt all aspects of precision farming. Table 6 offers a breakdown of how the costs could be distributed across different levels of acreage if one was to purchase all the equipment needed. These costs are ones that would be incurred over conventional methods. How the costs were calculated is mentioned next to each item in the table. Soil sampling results are assumed to be valid for an average of three years, therefore in this table the cost was depreciated based on that three year average. It was also assumed for all types of equipment and services that there was no salvage value. Labor was figured at an added half an hour per acre for learning, planning and implementing these new procedures at a rate of $7.20 an hour. Only some of the items were considered to have maintenance costs according to Richard Johnson's (NPA) experience and even those were minimal. The maintenance costs on the VRT air seeder was figured at $0.50/per $1,000 of investment cost times the average annual hours of use. Field capacity was calculated using the following formula (Kay and Edwards, 1994):

$$\text{Field Capacity} = \frac{\text{speed (mph)} \times \text{width (feet)} \times \text{field efficiency}}{8.25}$$

Speed was estimated at 4 mph (an average tractor speed), equipment width was 52 feet (for this particular John Deere air seeder), and efficiency estimated to be 85% (average for most seeders, Kay and Edwards, 1994). The field capacity, approximately 20 acres per hour was then divided into the acreage (i.e. 300, 600, etc) to find the average annual hours the seeder would be used.

At the bottom of Table 6 is a total cost and net returns per acre for each acreage category. The costs ranged from $85.13/acre at the highest for a 300 acre farm to $27.41/acre at the lowest for the 1,500 acre farm. Returns per acre were figured on a 10/bu/acre increase in production valued at $3.50/bu for a total return of $35/acre. Net returns ranged from $7.59/acre at the highest for a 1,500 acre farm to a loss of $50.13/acre at the lowest for a 300 acre farm.

Several other options are available besides investing in all of the equipment mentioned here. For example, a farmer could invest in a yield monitor with GPS capabilities and then have a consulting firm create the maps for variable rate applications and have service companies apply the inputs. This would probably decrease the amount of capital a farmer would have to invest in the beginning and probably reduce costs on the smaller acreages.

Table 6: Cost Estimate of Adopting All Precision Agriculture Technologies, Wheat Enterprise

Cost of Equipment	**300 acres**	**600 acres**	**900 acres**	**1,200 acres**	**1,500 acres**
GPS and DGPS ($3,000 receiver)					
Fixed					
Depreciation (7 year straight line)	$ 428.57	$ 428.57	$ 428.57	$ 428.57	$ 428.57
Interest (8% of average)	$ 120.00	$ 120.00	$ 120.00	$ 120.00	$ 120.00
Insurance (0.5% of average)	$ 7.50	$ 7.50	$ 7.50	$ 7.50	$ 7.50
Taxes (1.2 % of average)	$ 18.00	$ 18.00	$ 18.00	$ 18.00	$ 18.00
Overhead ($1/acre)	$ 300.00	$ 600.00	$ 900.00	$ 1,200.00	$ 1,500.00
Variable					
Yearly subscription fee ($800 annual)	$ 2.67	$ 1.33	$ 0.89	$ 0.67	$ 0.53
Total:	$ 874.07	$ 1,174.07	$ 1,474.07	$ 1,774.07	$ 2,074.07
Per Acre:	$ 2.91	$ 1.96	$ 1.64	$ 1.48	$ 1.38
Yield Monitor: $5,000					
Fixed					
Depreciation (7 year straight line)	$ 714.29	$ 714.29	$ 714.29	$ 714.29	$ 714.29
Interest (8% of average)	$ 200.00	$ 200.00	$ 200.00	$ 200.00	$ 200.00
Insurance (0.5% of average)	$ 12.50	$ 12.50	$ 12.50	$ 12.50	$ 12.50
Taxes (1.2 % of average)	$ 30.00	$ 30.00	$ 30.00	$ 30.00	$ 30.00
Overhead ($1/acre)	$ 300.00	$ 600.00	$ 900.00	$ 1,200.00	$ 1,500.00
Variable					
Maintenance ($400 possible yearly repairs)	$ 1.33	$ 0.67	$ 0.44	$ 0.33	$ 0.27
Total:	$ 1,258.12	$ 1,557.45	$ 1,857.23	$ 2,157.12	$ 2,457.05
Per Acre:	$ 4.19	$ 2.60	$ 2.06	$ 1.80	$ 1.64
Variable Rate Fertilizer					
Variable					
Custom Application (above conventional)	$ 600.00	$ 1,200.00	$ 1,800.00	$ 2,400.00	$ 3,000.00
Total:	$ 600.00	$ 1,200.00	$ 1,800.00	$ 2,400.00	$ 3,000.00
Per Acre:	$ 2.00	$ 2.00	$ 2.00	$ 2.00	$ 2.00

Table 6 Continued

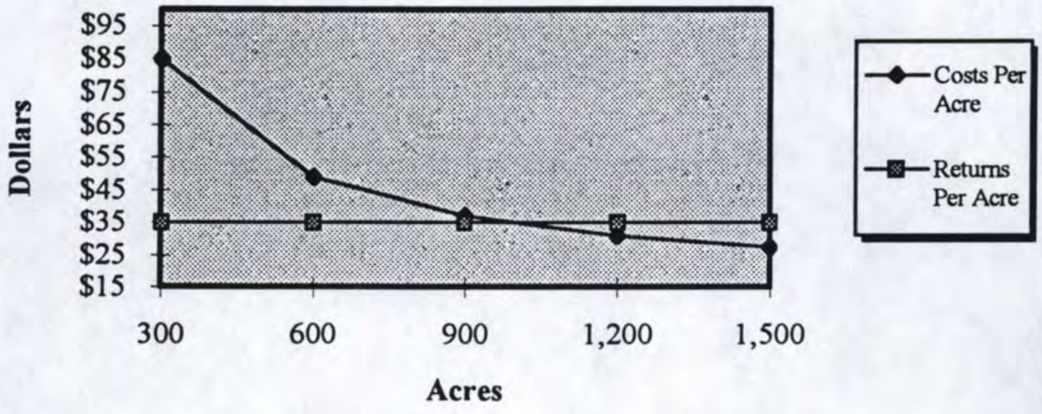
	300 acres	600 acres	900 acres	1,200 acres	1,500 acres
Geographic Information System ($10,000 package)					
Fixed					
Depreciation (7 year straight line)	$ 1,428.57	$ 1,428.57	$ 1,428.57	$ 1,428.57	$ 1,428.57
Interest (8% of average)	$ 400.00	$ 400.00	$ 400.00	$ 400.00	$ 400.00
Insurance (0.5% of average)	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00
Taxes (1.2 % of average)	$ 60.00	$ 60.00	$ 60.00	$ 60.00	$ 60.00
Overhead ($1/acre)	$ 300.00	$ 600.00	$ 900.00	$ 1,200.00	$ 1,500.00
Total:	$ 2,213.57	$ 2,513.57	$ 2,813.57	$ 3,113.57	$ 3,413.57
Per Acre:	$ 7.38	$ 4.19	$ 3.13	$ 2.59	$ 2.28
Variable Rate Technology ($95,000 air seeder)					
Fixed					
Depreciation (7 year straight line)	$ 13,571.43	$ 13,571.43	$ 13,571.43	$ 13,571.43	$ 13,571.43
Interest (8% of average)	$ 3,800.00	$ 3,800.00	$ 3,800.00	$ 3,800.00	$ 3,800.00
Insurance (0.5% of average)	$ 237.50	$ 237.50	$ 237.50	$ 237.50	$ 237.50
Taxes (1.2 % of average)	$ 570.00	$ 570.00	$ 570.00	$ 570.00	$ 570.00
Overhead ($1/acre)	$ 300.00	$ 600.00	$ 900.00	$ 1,200.00	$ 1,500.00
Variable					
Maintenance & Repairs (same as conventional)	$ 712.50	$ 1,425.00	$ 2,137.50	$ 2,802.50	$ 3,515.00
Total:	$ 19,206.43	$ 20,233.93	$ 21,261.43	$ 22,240.43	$ 23,267.93
Per Acre:	$ 64.02	$ 33.72	$ 23.62	$ 18.53	$ 15.51
Custom Soil Sampling ($14/acre)					
Fixed					
Depreciation (3 year straight line)	$ 4.67	$ 4.67	$ 4.67	$ 4.67	$ 4.67
Interest (8% of average)	$ 0.56	$ 0.56	$ 0.56	$ 0.56	$ 0.56
Insurance (0.5% of average)	$ 0.04	$ 0.04	$ 0.04	$ 0.04	$ 0.04
Taxes (1.2 % of average)	$ 0.08	$ 0.08	$ 0.08	$ 0.08	$ 0.08
Overhead ($1/acre)	$ 300.00	$ 600.00	$ 900.00	$ 1,200.00	$ 1,500.00
Total:	$ 305.35	$ 605.35	$ 905.35	$ 1,205.35	$ 1,505.35
Per Acre:	$ 1.02	$ 1.01	$ 1.01	$ 1.00	$ 1.00
Labor					
Variable					
Learning, planning and implementing time	$ 3.60	$ 3.60	$ 3.60	$ 3.60	$ 3.60
Total:	$ 1,080.00	$ 2,160.00	$ 3,240.00	$ 4,320.00	$ 5,400.00
Per Acre:	$ 3.60	$ 3.60	$ 3.60	$ 3.60	$ 3.60
Total Precision Ag Package:	**$ 25,540.20**	**$ 29,445.70**	**$ 33,352.54**	**$ 37,211.20**	**$ 41,118.50**
Total Costs Per Acre:	**$ 85.13**	**$ 49.08**	**$ 37.06**	**$ 31.01**	**$ 27.41**
Returns from increased yields					
Variable					
Yield increase of 10bu/acre @ $3.50/bu	$ 35.00	$ 35.00	$ 35.00	$ 35.00	$ 35.00
Total:	$ 10,500.00	$ 21,000.00	$ 31,500.00	$ 42,000.00	$ 52,500.00
Returns Per Acre:	$ 35.00	$ 35.00	$ 35.00	$ 35.00	$ 35.00
Total Net Returns Per Acre:	**$ (50.13)**	**$ (14.08)**	**$ (2.06)**	**$ 3.99**	**$ 7.59**

*See Footnote at the end of Table 4.

Sources: Northwest Precision Ag, Madison Farms, Nickell Farms, and Kay and Edwards (1994).

A visual depiction of the numbers in Table 6 can be seen in Figure 5. As it is with many other aspects of farming, when size increases the costs per acre decrease. The larger farm has an advantage. However, it might be feasible for a couple of smaller growers to get together and share some of the expenses if they feel the benefits of a larger enterprise are worthwhile. This shows an estimated breakeven acreage to be around 1,000 acres if a grower was to adopt all aspects of precision agriculture. Again, a grower could use his or her own costs in Table 6 to estimate a breakeven point for their operation.

Figure 5: Estimated Additional Costs Per Acre for a Wheat Enterprise Adopting All Aspects of Precision Agriculture



Case Studies

David Zilberman (1998) compares the adoption of drip irrigation technology to that of precision agriculture. He has found that the major factors affecting the adoption of precision technologies are prices of outputs and inputs, and environmental characteristics. History also shows us that extreme events such as droughts and high or low prices often trigger large-scale adoption of new technologies. The literature on adoption in agriculture (Putler and Zilberman, 1988) says that education affects the adoption of computers and that for a complex technology adoption is slow and piecemeal. He goes on to say that size isn't as important as the crop, its location and the availability of equipment and a support system. However, as with any production, costs are prohibitive unless a critical mass can be accumulated.

The following are individual cases where a grower has adopted some or all aspects of precision agriculture and been successful.

Farming Operations

Madison Farms

Kent Madison of Madison Farms in Echo, Oregon is currently farming 6,736 acres of irrigated land that has been in his family for nearly 90 years. They grow a wide variety of crops including alfalfa, canola (both seed and crush), buckwheat, spring wheat, winter durham wheat, corn, potatoes, soft white winter wheat, clover and others. The Madison's began with precision farming five years ago when they purchased a yield monitor. Kent's goal when he made this initial purchase was to "stay in business", which meant increasing production or decreasing expenses or some combination of the two. He feels that he needs to be in the forefront of technology to keep his farm competitive, and so far it is working. Before purchasing a yield monitor, Madison Farms already had an advanced computer system in place to keep track of records, billing, and even which employee checked problems in specific fields. He has a very detailed history of what has been going on in the fields, which has aided him in the adoption process. Kent considers it to be a learn as you go process because each day and season bring new challenges. With five years of data he now has a significant database, but cautions others to not make any hasty changes or decisions.

He has not used a consultant to aid him in this process, and in fact has been teaching others about precision agriculture at conferences. They do hire an area supplier to do variable rate fertilizer applications. They have also recently purchased a variable rate seeder, and are planning to use it this coming season.

When asked if precision agriculture has paid, Kent definitely believes it has, but notes that he expects the real payoffs to be several years down the road. The annual cost per acre for soil sampling on his farm was $25, which included soil sampling, grid mapping and nutrient recommendations. He saved almost $10/acre in fertilizer costs with variable rate applications and his quality and quantity of products has increased by nearly $20/acre, giving him an average $5/acre increase in profits over and above the expense of precision agriculture.

Nickell Farms

Greg Nickell runs an 1,800 acre irrigated farm near Blackfoot, Idaho. Nickell Farms' major crops are potatoes and wheat. In the fall of 1996 he began to add precision farming technology to his operation by soil sampling 400 acres that were to be planted into potatoes in the spring of 1997. Samples were taken from one-acre grids and then the necessary soil amendments were applied based on soil test results. The next fall he used a yield monitor during harvest and has spent time this past winter going over the yield maps generated from that harvest. Greg has invested in precision technologies because he feels that in order to stay in business he needed to find a way to improve his productive capacity and also reduce costs. He believes that precision farming has the capability to do just that.

This season he is using some more precision technologies. Nickell Farms is experimenting with swath guidance and so far has been pleased with the results. They are also installing a precision irrigation system.

Mr. Nickell has also been using the help of consultants from Northwest Precision Ag (NPA) during this development phase of precision agriculture. They have been a good support while experimenting with new ideas. He also notes that during this time of learning labor is more intense than usual, but has still seen an increase in profits. As far as costs, his complete soil sampling package ran him $14/acre, his grain yield monitor with GPS was $8,000 and his potato yield monitor was $6,000. Nickell Farms already had a computer system in place when they started precision agriculture but did purchase a GIS software package called MapInfo for $1,800. NPA is helping with consulting and other information services but does not apply fertilizer or chemicals themselves. That work is hired out to other companies who have equipment capable of variable rate application. Currently, they are charging an extra $6.00-$8.00/acre for custom variable application of one input.

Palouse Farmer

One grain farmer in the Palouse area uses a yield monitor and mapping to identify areas of the farm that are of similar yield potential. These areas are farmed as separate units with seed, fertilizer, etc. based on the yield potential of each area. This gives some of the advantages of yield mapping without the expense of variable rate equipment to apply seed, fertilizer, and chemicals. Soil testing could also be readily used with this system. This is one way of getting started without a huge overhead of costs in the beginning.

Custom Operator

Dugger Enterprises

Kirk Dugger has a custom harvesting operation in eastern Washington and has just begun using precision agriculture. Dugger Enterprises last year harvested over 3,000 acres of wheat, barley and bluegrass. Last June a yield monitor was mounted into his combine by a research team from Washington State University. Kirk wanted to help with the research because he felt it would benefit him with knowledge of how precision technology works. He charges his customers by the hour and not the acre for his services. He sees the potential for irrigated farming to really benefit from this technology because of the inputs that are more controlled in that environment. Also the output is often more valuable. He is still working on what to charge for precision ag services.

Dealerships

Several commercial companies have become involved with supplying various types of equipment and technology used in precision agriculture. Some major machinery dealers sell yield monitors and other precision equipment either with harvesting machines or separately. Many other companies supply precision equipment along with consulting and servicing.

Probably the most active in precision agriculture in the early stages are the fertilizer and chemical dealers. They are especially promoting precision fertilizer application and can arrange for soil testing and mapping needed prior to precision application. This service has been promoted extensively on high value crops such as potatoes and sugarbeets. By this means a farmer can use precision application without owning or operating any extra equipment. A yield monitor for checking on site specific productivity would be a nice addition to see how effective the fertilizer program is. Some custom harvest operators can provide this service.

Summary and Conclusions

There are many aspects to precision agriculture. The global positioning systems, which make it all possible, yield monitors, soil sampling, geographic information systems and variable rate applications, when integrated, create an opportunity for those involved in production agriculture to become even better managers of their lands. Precision agriculture, while still in its infancy, has the potential to change the future of farming. There are many unknowns at this point and it can be an ongoing learning process, yet as technology continues to improve so will the application of precision agriculture. At the present time much of the equipment is too expensive for many growers to justify purchasing without the guarantee of financial benefits. However, the expense of equipment and services will probably also decline as technology advances, which will enable even more farmers to adopt.

The growers consulted in this paper have determined that in their operation(s) precision agriculture is profitable. However, they are both large, irrigated operations producing high valued crops, which have been indicated by other studies (Lowenberg-DeBoer and Swinton, 1995) as some of the attributes common to operations that have considered precision agriculture technologies to be profitable.

Many farmers have found precision agriculture to create more questions than answers, but studies are being conducted all around the world trying to find answers. The economics of this technology is an area of interest to most producers and where research is the most lacking. However, due to the numerous variables involved with producing any agricultural commodity, determining the profitability of precision agriculture will be very difficult. Despite the unknowns, early adopters have found that the positive attributes are often outweighing the costs. Precision agriculture allows farm operators to develop more complete information and farm each part of the field for optimum production.

Adopting precision agriculture technologies requires a farmer to re-think his method(s) of operating. More time and planning will be needed before reaching the fields, and farmers will have to assess an ever-increasing amount of information. Having more information may seem to be a complication, but the more one knows about what is happening in one's fields, the better decisions can be made.

Another benefit derived from precision agriculture is better protection of the environment. Using no more chemicals or water than needed in a field will reduce runoff, sedimentation and contamination of water. In this regard, precision agriculture is closely related to soil conservation.

Farm operators, however, are mainly interested in increasing net returns through added yields, reduced costs or a combination of the two. Yield monitoring, soil sampling, and field scouting provide information needed for better decision making. Precision or site specific applications provide a way to make optimum use of information.

The adoption of precision agriculture is really a decision making process. A grower considering using one or all aspects should thoroughly research all of the products and services available before starting. The process continues even after getting involved due to the constant accumulation of information and because of the continual changes in technology and knowledge. The more educated one is about precision agriculture, the more likely one is to make profitable decisions concerning it. Also, one should be aware that precision farming is still in the development stage. No doubt, more efficient and improved systems will be developed in the future.

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Appendix

Planning Guidelines

Before a farmer starts with precision agriculture, he should thoroughly investigate all aspects. PrecisionAg Illustrated offered some do's and don'ts for adopting precision agriculture technology. They summarize the main points mentioned in this paper and are as follows:

DO'S

1) Take the time to develop a precision plan with goals that mesh with other business plans on the farm.
2) Design your entry into precision as if it were a research project. Do research that helps you learn more about your crop production potential.
3) Learn from the mistakes of others. Use resources to gain information on what is happening, what is and is not working.
4) Research all precision equipment. Look past the sales pitch and hype. Look for a good track record and service availability.
5) Be patient. Start out reasonably and develop precision one step at a time.
6) Have reasonable expectations. Make precision work for you, and look for early results in areas that are obvious and practical.
7) Use an open-ended approach. Be sure software, hardware and raw data can be used in an expandable and flexible manner. Use the GIS engines that won't lock you into one way of analyzing and viewing data.
8) Find a precision agriculture company or specialist. There are companies and individuals who have precision experience.
9) Be meticulous; your data is not forgiving. Back up your raw data and make sure equipment is operating properly.
10) Calibrate equipment when you change fields or varieties or when environmental conditions change.
11) Find and use what will fit your needs and plans, and implement them in a manner consistent with your program.
12) Use a board of directors for input and involve them in the process. That board might include your banker and agronomist or other family members. They need to be involved or you may not have their support.

DON'TS

1) Don't use the shotgun approach once you start precision farming. Stick with it. Building a comprehensive database is important. You can't skip a few years due to crop rotation.
2) Don't take short cuts. For example don't use one yield monitor if you have two combines in the same field or section. Split them up so you have one monitor in the whole field or section to get complete data. Half a field of yield is really useless information.
3) Don't forget you have a farm to manage. Don't take on more than you can handle, and don't do more than you can afford. Bring a precision agriculture specialist or consultant, and use their resources.
4) Don't read more into the data maps than might really be there. You need good answers, data and feedback. Be reasonable in your approach.
5) Don't apply short-term thinking to a long-term project. Always have the end in mind. Don't get distracted along the way.
6) Don't use sporadic precision agriculture practices or approaches. Focus and maintain that focus. Apply precision technology to the whole field not just a part (Unless you are comparing results in a planned test.)
7) Don't approach precision in a half-hearted manner, it's a management decision and deserves your full commitment. Train your employees to pay attention to detail.
8) Don't assume anything. If you think it is not working, go check it out. If you feel something isn't working, then it probably isn't.

Once one knows that this is a viable option for their operation, they should write down what exactly they expect to get out of adopting precision agriculture. The following is a guideline for setting farm goals with precision agriculture.

A. Goals: Outline for yourself ahead of time what you expect to achieve with this new investment. Try asking yourself questions like these:

- Why do you want to use precision technologies?
- Where do you want to start? With a yield monitor, soil sampling, etc?
- What can you afford right now? Next year?
- How much time are you willing and able to put into this project?
- Where will you get answers to questions when they arise?
- How soon do you expect to see returns?

B. Research: Always begin by thoroughly researching equipment, dealers, support help, and talk with other growers who have tried the same things. Some questions you should ask when researching are:

- What are the prices?
- Is leasing an option?
- Is the equipment compatible with equipment you already have?
- Is the equipment capable of upgrading?

C. Implement: Be patient with yourself and the equipment. Be realistic, but don't limit yourself. Take the extra time to become comfortable with this new technology. Plan your days ahead of time because getting started isn't always easy and nothing ever goes as planned; however organization will save you some headaches.

D. Evaluate: Getting started is often a trial and error process. Even something that worked for a neighbor or friend won't necessarily work for you. Decide what did work, and stick with it. The things that did not work maybe need some more research. Think about what your next step is going to be so that you can reach your goals.

Source: Richard Johnson, Northwest Precision Ag.

Precision Agriculture Suppliers and Resources

Table 8: A listing of on-line support and suppliers of precision agriculture technologies.
(note: all internet links begin with http://)

General Precision Farming Links

University Sites

Purdue University Electronic Precision Farming Institute
pasture.ecn.purdue.edu/~mmorgan/PFI/
Precision Farming at UGA
www.bale.uga.edu/dept/research/precision/index.html
Precision Farming Center -- Bjertorp
ugis2.arch.chalmers.se/jord/pfcb_p1.htm
Centre for Precision Farming
www.cranfield.ac.uk/safe/cpf/
CSANR Home Page
www.cahe.wsu.edu/~drycrops/
Precision Agriculture
www.soils.agri.umn.edu/research/precise-agri
Texas Precision Agriculture Taskforce
ageninfo.tamu.edu/~searcy/task.html

Sales and Service

John Deere: Precision Farming
www.deere.com/greenstar
Case Advanced Farming Systems
www.casecorp.com/agricultural/afs.index.html
New Holland Precision Land Management System
www.newholland.com/na/pfs/index.html
@g Online WEATHER
www.agriculture.com/technology/index.html
The GROWMARK System Online
www.growmark.com
Welcome to Precision Agriculture
www.precisionag.com
Welcome to Horvick Manufacturing
www.horvick.com
AGRIS
www.agris.com
Midwest Technologies, Inc.
www.mid-tech.com
Agri-Logic
www.agrilogic.com

Miscellaneous

Precision Agriculture Messages
www.agriculture.com/agtalk/Precision_Agriculture/listmsgs.cgi
Partners in Precision
www.smartfarm.com/
Precision Farming Mega-Links
nespal.cpes.peachnet.edu/pf/
Association of Agricultural Computing Companies
asae.org/aacc/
Potash & Phosphate Institute
www.agriculture.com/ppi/index.htm
Simon Blackmore's Bookmarks for Precision Farming
www.cranfield.ac.uk/safe/cpf/links/SBBookmarks.htm
Agri-Alternatives On-Line
www.agrialt.com/index.shtml
Northwest Precision Ag
www.nwpag.com
Idaho Precision Ag Association
www.ipaa.com

Variable Rate Technology Links

University

Variable Rate Application Equipment for Precision Farming
www.bae.uga.edu/dept/research/precision/clark_vrt.html#over

Sales & Service

CTI HomePage
www.soildoctor.com
Tyler Industries, Inc.
www.teamtyler.com
Ag-Chem Equipment Co., Inc.
www.agchem.com

Table 8 continued

GIS/Mapping Links

Applications Mapping
www.agriculture.com/misc/harford/am.html

Cotton Simulation and GIS
www.mcs.com/~mccauley/WWW/bib/resolution-abs.html

GIS World, Inc.
www.gisworld.com/main.html

ESRI GIS Software
www.esri.com

MapInfo Map Database Software
www.mapinfo.com

World Database on Irrigation and Hydrology Software
www.wiz.uni-kassel.de/kww.irrisoft/irrisoft_i.html

Geospatial Support Staff
www.blm.gov/gis/gishome.html

Farm Works
www.farmworks.com

International Benchmark Sites Network for Agrotechnology Transfer
everex.ibsnat.hawaii.edu/general/info.htm

GeoPlace
www.geoplace.com

Farmer's Software Association
www.farmsoft.com

Innovative GIS Solutions, Inc.
www.innovativegis.com/

Remote Sensing Links

RSRU Homepage
rsru2.tamu.edu/rsru/site/specific.htm

Environmental Remote Sensing Laboratory Homepage
doppler.unl.edu

NASA/JPL Imaging Radar Home Page
southport.jpl.nasa.gov

Remote Sensing and GIS Information
www.gis.umn.edu/rsgisinfo/rsgis.html

GPS Links

University/Government

Global Positioning System Overview
www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html

MIT/LL GLONASS & GPS Home Page
satnav.atc.ll.mit.edu

GLONASS
www.rssi.ru/SFCSIC/glonass.html

US Coast Guard Navigation Center
www.navcen.uscg.mil/navcen.htm

Sales and Service

The Starlink DGPS Pages: Home Page
www.starlinkdgps.com/home.htm

Welcome to Ashtech
www.ashtech.com

DCI's DGPS and TMC Services
www.dgps.com

RTK America Corporation
www.inforamp.net/~pinpoint

OMNISTAR
www.omnistar.com

Trimble Navigation Limited
www.trimble.com

NovAtel Communications Limited
www.novatel.com

The SATLOC, Inc. Home Page
www.satloc.com

Rockwell -- Collins Avionics & Communications
www.cacd.rockwell.com

GPS World
www.gpsworld.com

Source: The Precision-Farming Guide for Agriculturists.

Table 9: A listing of companies and the precision farming products they offer.

Company	Navigation/ location systems	Metering/ application equipment	Yield monitors	Computer mapping/ software	Other
Ag Chem Equipment Co. (612) 933-9006	X	X			Falcon MD Control Systems
AGCO (770) 813-9200		X			
Ag Leader Technology (515) 232-5363			X		
Agri-Logic, Inc. (800) 444-8214	X			X	
Agris Corp. (800) 795-7995		X	X	X	Crop record-keeping and accounting software
Ashtech Springhill Engineering Division (800) 850-6970	X				
Case IH (414) 636-6011	X	X	X	X	AFS System
Cenex/Land O'Lakes Ag Services (612) 451-4586				X	
Chandler Equipment Co. (800) 243-3319		X			
Deere & Co. (309) 765-8000	X	X	X	X	Green Star
Del Norte Technology, Inc. (800) 245-DNTI	X				
Dickey-john Corp. (800) 637-2952		X			
Differential Correction Inc. (DCI) (408) 446-8350	X	X	X		
Gandy Co. (800) 443-2476		X			
Harvest Master (801) 753-1881			X		
INSAT, L.C. (868) 467-2899	X				
Lor★Al Products Inc. (320) 843-4161	X	X			Falcon MD Control Systems
Micro-Trak Systems (507) 257-3600	X	X	X		

Table 9 continued

Company	Navigation/ location systems	Metering/ application equipment	Yield monitors	Computer mapping/ software	Other
Midwest Technologies, Inc. (217) 753-8424		X			
New Holland (717) 355-1121					Yield monitor under development to be available in 1997
NovAtel GPS (403) 295-4500	X				
RDI Technologies, Inc. (800) 221-7348				X	
Rockwell International (319) 395-2027	X			X	Variable-rate application/planter console
SATLOC Inc. (602) 831-5100	X			X	
Software Solutions of Illinois, Inc. (800) 752-7912				X	
Spraying Systems Co. (708) 665-5000		X			
Thurston Manufacturing Co. (800) 658-3127		X			
Trimble Navigation Ltd. (800) 545-7762	X				
Tyler, Inc. (800) 328-9128	X				
WAG Corp. (601) 844-8478	X		X	X	
Willmar Manufacturing (612) 231-9400	X				
ZYCOM Corp. (617) 274-1222	X				

Source: Doane's Guide to Precision Farming

Glossary

Archive – the storage of historical records and data. When you have collected a year or two of data from your precision farming applications, you have started you own archive.

American Standard Code for Information Interchange (ASCII) – A standard coding system used to represent alphanumeric characters within a computer. ASCII files enable the transfer of some data between different computers through the use of a common set of symbols.

Aspect – Horizontal direction in which a slope faces (i.e. a SE facing slope has an aspect of 135 degrees).

Base Map – The outline of your field with its proper coordinates is your base map. Data collected within the field by your yield monitor will be defined in location by the base map, which is a binary digital map.

Baud Rate – A measure that describes the speed of the transmission of single digital elements over a communications line. The number indicates how rapidly data could move through your modem or between a computer and a printer.

Byte – A unit of computer storage of binary data usually comprising eight bits, and equivalent to a character. You will commonly hear computer memory and storage referred to using terms such as Kilobyte (approximately one thousand bytes), Megabyte (approximately one million bytes) and Gigabyte (approximately one billion bytes).

Channel – Circuitry necessary for a GPS receiver to receive the signal from a single GPS satellite.

Crop Scouting – Visual assessment of crop condition including growth stage/maturity, plant vigor, presence of disease, weed infestation, and insect infestation..

Database – A logical collection of files managed as a unit. GIS databases include data about both the position and the attributes of geographic features.

Data input – The entry of information into a computer through the use of a keyboard, digitizer, scanner, or even entering data from already existing databases.

Differential GPS (DGPS) – Since the GPS signal is encoded for defense purposes, this added signal is required for the accuracy needed with farming applications. This differential signal can come from a variety of sources – a second satellite, a signal from the U.S. Coast Guard, or a local FM transmission.

Georeferenced Data – Spatial data that pertains to specific locations on the Earth's surface.

Global Positioning System (GPS) – A network of satellites controlled by the Defense Department that are designed to help ground based units determine their current location in latitude and longitude coordinates. This technology helps you locate yourself in the field.

Geographic Information Systems (GIS) – System of computer hardware, software, and procedures designed to support the compiling, storing, retrieving, analyzing and display of spatially referenced data for addressing planning and management problems. Don't confuse GPS with GIS. GPS tells you where you are; GIS is used to create decision-making maps.

Grid – A data structure that uses rectangular units or grid cells arranged in rows and columns to represent an area like a field (does not have to be rectangular, just symmetrical).

Grid Sampling – A process of dividing a filed into the smallest potential unit for collecting soil samples. This process may or may not require a GPS locator for best results depending on the technique used. The key is using a grid small enough to provide useful, accurate information. If the grid is too large the averaging information won't be specific enough for variable-application purposes.

Grid Mapping – Predetermined locations in a field where soil samples are obtained for analysis. The test information can be used for assessing fertility needs and determining approximate locations for varying applications.

Hardware – The various physical components of an information processing system such as a computer, screen, plotters and printers.

Interpolation – A procedure for predicting the unknown values between neighboring known data values.

L-Band – The segment of the radio spectrum ranging in frequency from 1,000 to 2,000 MHz.

Latitude/Longitude (LAT/LONG) – A coordinate system which identifies a position on earth. Latitude is the north to south position. Longitude is the east to west position. Locations are described in units of degrees, minutes and seconds.

Load Cell – A device that converts a force or weight into an electrical signal.

Layer – Mapped information of a specifically identified characteristic such as soil type, yields fertility, or vegetation. Each map layer displays the variability for that specific data set within the designated field.

Legend – A map section containing explanations of symbols, colors and/or shades that signify various elements and data values on the map. A yield map will contain a listing of yield values and the color denoting a range of yields.

Mapping Software – See Geographic Information Systems.

Menu – A list of options displayed by a computer data processing program, from which the user can select an action to be initiated. These choices are usually displayed in the form of alphanumeric text but may be as icons.

Merge – To take two or more maps or data sets and combine them together into a single coherent map or database without redundant information.

Multispectral – Capable of detecting electromagnetic radiation from multiple spectral bands simultaneously.

Panchromatic – Images created from radiation with wavelengths between 0.45 and 0/90 μm, usually produced in grayscale (black and white).

Parallel Swathing – Driving (or flying) a vehicle in straight, parallel paths without leaving gaps or overlapping consecutive paths (swaths).

PCMIA card (PC card) – A small credit-card-size data storage device used by most yield monitors.

Pixel – A term used in remote sensing referring to the fundamental unit of data collection which is an abbreviation for "picture element". A pixel is represented in a remotely sensed image as a rectangular cell in an array of data values and contains a data value that represents a measurement of some real-world feature.

Point Sampling – A method of grid sampling in which a sample is taken in a 10-30 foot radius at the center point of each grid location.

Remote Sensing – The act of detection and /or identification of an object, series of objects, or landscape without have the sensor in direct contact with the object. It is used to gauge the health of the crop on a real-time basis in order to help make application decisions.

Roving – The field equipment that is moving around the field

Scale – The ratio or fraction between the distance on a map, chart, or photograph and the corresponding distance on the ground. A topographic map has a scale of 1:24,000 meaning that 1-inch on the map equals 24,000 inches (2,000 feet) on the ground.

Spectral Response – 1) characteristic patterns of radiation reflected or emitted from an object. 2) the ability of a sensing system to respond to radiation measurements within a spectral band.

Spectral Resolution – The ability of a sensing system to differentiate between electromagnetic radiation of different wavelengths.

Software – The programs, procedures, algorithms, and their associated documentation, for a computer system (i.e. Microsoft Word and Excel).

Spatial Data – Data pertaining to the location, shape, and relationship among geographical features.

Thematic Map – A map related to a topic, theme or subject. These maps emphasize a single topic such as yield, soil type, or land ownership.

Variable Rate Technology (VRT) – Instrumentation used for varying the rates of application of fertilizer, pesticides, and seed as one travels across a field.

Yield monitor – Regular intervals where a harvested weight has been obtained along with a GPS reading. A display of the weights translated to bushels/acre or yield provides a yield map.

Sources: Chris Johannsen, Precision Farming Institute, Glossary of Terms for Precision Farming and The Precision-Farming Guide for Agriculturists.