ECONOMICS OF PRECISION AGRICULTURE

Module Outline

1.0 ECONOMICS OF PRECISION AGRICULTURE

1.1 Economics is the study of how people make decisions. A common economic decision that farmers make is whether doing something will return more than it costs. This decision is made in a business situation, where returns are measured in dollars. Economics is easy to explain in a business setting because we can use dollar measures. But people make economic decisions every day, whether they are in business or not. For example, deciding how much nitrogen to put on your corn this year, whether to buy a shirt or go out for lunch, or whether to attend a farmer's meeting or spend time fishing are all economic decisions. The concepts may be harder to grasp when costs and returns are not measured in dollars terms, but the concepts are still the same.

Sections 2.0 to 8.0 are presented for students who do not know a lot about economics or how economics is used in managerial decision making. For some of you these sections will be an introduction to the material, while for others they will be a review. Whatever your level of economic understanding, it is strongly suggested that you carefully read sections 2.0 to 8.0 to fully understand the applications of economics to precision agriculture found in sections 9.0 to 13.0.

1.2 Economic decisions involve allocating resources to reach a goal. The goal may be to make as much money as you can, or to grow the largest cantaloupe in the county, or to catch the largest wide-mouth bass caught this year. Whatever the goal, the basic economic decision framework is the same: what are the costs, in dollars, time or effort, compared to the benefits?

This section explores a few basic concepts from economics and shows how these concepts are used in decision making. Situations from agriculture are used to illustrate the applications of these concepts.

2.0 ECONOMICS IS …

2.1 Economics is a social science that studies how people allocate their limited resources. If resources are not limited, then we do not have to make economic decisions on how to allocate them. For example, air is not limited, so it is not necessary to decide how many breaths to take in the morning and many to save for your afternoon tennis game. Time, on the other hand, is very limited. The more time you spend working, the less time is available for tennis. Money is also limited. The more you spend on food, the less is available for other goods and services.

2.2 Utility is …

People generally allocate their limited resources in such a way that they will receive the greatest return from them. In a business setting the goal may be to maximize profits. However, other goals also may be important. In other words, the greatest return is not necessarily the same thing as the greatest profit. Economists at one time thought that profit was the goal all farmers, but economists now realize that producers and consumers may have multiple goals and objectives. A farmer most likely wants to make a profit, but may at the same time want to be recognized as a community leader, a of champion conservation practices and spend time with the family. This farmer may have multiple goals and objectives, some of which may even be competing with each other while others may be complementary.

Economists refer to the satisfaction received from this mix of activities as "utility". Utility is the satisfaction one receives from consuming a good or a service or engaging in some activity. Profit may determine to a large degree the utility a farmer receives from growing corn, but other factors contributing to the farmer's utility may be having the highest yield per acre, doing a good job and being one's own boss. Many different factors beside economic profit can add to the utility a farmer receives from growing corn.

The idea that farmers may be trying to maximize their total utility rather than their profit is an important concept when it comes to evaluating new technology. Some level of profits is necessary for a business to survive, but a farmer who is doing something that is inconsistent with profit maximization is not necessarily irrational. The farmer may be receiving utility from actions other than profit maximization. (Some farmers may not even be concerned with making a profit, but are engaged in agriculture as a leisure activity or as a hobby.)

Many studies have shown that farmers are more concerned with minimizing their risk of losing money than with making all the money they can. That is, the loss of utility associated with losing money is greater than the utility gained from a high-risk enterprise.

Throughout this section we will assume that farmers have multiple objectives which are related but slightly different. They want to maximize profits from their farming operation, they want to minimize the costs of producing their crops and they want to minimize their down-side risk, i.e., they don't mind making more money than they expected, but will take steps to make sure they don't lose money.

2.3 Marginality is ….

An important concept is "marginality". This concept specifies that more resources should be used as long as the marginal (additional) benefit from the additional resource exceeds its marginal cost. This concept is easiest to explain with an example. The yield records for corn grown on a sandy loam soil given different amounts of nitrogen fertilizer are reported in Table 1. Without any nitrogen fertilizer the yield is only 45 bushels/acre. When 20 pounds of fertilizer are applied, the yield increases to 84 bushels. When fertilizer is doubled to 40 pounds, the yield does not double, but it does increase by 26 bushels. As fertilizer is increased by additional 20-pound increments, the corn yield increases, but by smaller and smaller amounts, as shown in Figure 1. The maximum amount of fertilizer this crop can use is about 120 pounds per acre. More than 120 pounds per acre and the crop is "burned" by too much nitrogen.

Table 1. Corn Yield and Dollar Values at Different Rates of Fertilizer.

Nitrogen Fertilizer (lbs)	Corn Yield (bu)	Value of Fertilizer ($0.25/lb)	Value of Corn ($3/bu)`	Net Return	Cost of Added Fertilizer	Change in Net Retrun
0	45	$ 0	$135	$135		
20	84	5	252	247	$5	$112
40	110	10	330	320	5	73
60	127	15	381	366	5	46
80	137	20	411	391	5	25
100	140	25	420	395	5	4
120	141	30	423	393	5	-2
140	138	35	414	379	5	-14

Economists call this phenomenon the "Law of Diminishing Returns". Diminishing returns exist in all aspects of agricultural production. An increase in fertilizer causes an increase in yield, but the yield will increase in smaller and smaller amounts as the fertilizer is increased. Give a cow more feed and she will give more milk, up to a point, but the increase in feed will cause ever smaller increases in the amount of milk produced. Diminishing returns holds for all inputs, even information. You can expect an increase in crop yield and/or quality by testing soil moisture and irrigating appropriately. The benefits of testing once a week rather than once a month are likely to be significant. However, there may not be a significant increase in benefits from testing soil moisture every 12 hours rather than every 24 hours.

The economic question is "At what point is the return from the additional yield worth the cost of the additional fertilizer (or feed or information)?" There is no single point, as the "right" amount of fertilizer depends on the prices of fertilizer and corn.

Suppose our corn farmer expects to sell corn for $3.00/bushel and nitrogen costs $0.25/pound. At these prices, an additional 39 bushels are worth $117, an additional 20 pounds of nitrogen costs $5.00, and the additional net return is $112. Twenty more pounds of nitrogen cost an additional $5.00 and produce additional 26 bushels of corn, which is worth $78, for an added net return of $73. And so forth. As long as the additional fertilizer costs less than the dollar value of the additional corn yield, it is profitable to apply more fertilizer.

The net return (total value of the corn minus the total cost of the fertilizer) is reported in column 5 of Table 1. The greatest gross margin occurs when 100 pounds of fertilizer are applied per acre. The net return is lower if either more or less nitrogen is applied. This can also be seen by comparing the change in value produced with the additional cost of fertilizer. As long as the additional value produced is greater than the additional cost, the net change in returns will be positive.

In real life farmers don't consciously work out tables of added costs and returns, and yet most farmers can tell you doing something differently or adding more of an input would increase yields, but the costs of doing so would out weigh the returns. However, the concept of marginality is central to looking at the economics of a situation. In the example above, we looked at the costs and returns of using more nitrogen on a corn crop "at the margin". When evaluating precision agriculture systems, you should compare the added costs and the added returns from that system, at the margin.

2.4 Relative prices …

In the example above, the "right" amount of nitrogen fertilizer was found given the current prices of corn and nitrogen. As prices change, so does the "right" amount of nitrogen. If corn falls to $1.65/bushel, the cost of producing 3 more bushels of corn (from 137 bushels to 140 bushels/acre) is still $5 worth of fertilizer, but the added returns from that fertilizer are only $4.95 of additional corn.

2.5 Multiple Enterprises

The concept of marginality still applies even when there is more than one input or output. It becomes a bit more complex, however, when there are two or more outputs, and a limited amount of an input.

Suppose you have two possible crops, corn and wheat, with a schedule of added costs and returns from fertilizer as reported in Table 2. The marginality concept tells us to apply five units of fertilizer to both the corn and the wheat. However, if resources are limited to a total of only five units of fertilizer, you cannot set added costs equal to added returns for crops to determine the right amount of fertilizer to use. The basic marginality concept stills holds, but you will be restricted to applying the limited amount of fertilizer first to the crop with the highest return, then to the next highest return, etc. In Table 2, the first unit of fertilizer should go to the corn. The added return from one unit of fertilizer is greater from corn than from wheat ($117>$80). The second unit, however, should go to wheat. The return of one unit of fertilizer on wheat is greater than the second unit on corn ($80>$78). The third and fourth units should go to corn, and the fifth the wheat.

Table 2. Data Illustrating the Equi-Marginal Principle

		Added Value Produced Due to Added Fertilizer	
Fertilizer (20 lb units)	Cost of Added Fertilizer	Corn	Wheat
1st	$5	$117	$80
2nd	5	78	50
3rd	5	51	28
4th	5	30	24
5th	5	9	8
6th	5	3	4
7th	5	-9	1

Always allocating a limited resource to the activity with the highest added return is called the "equi-marginal principle". Following this principle ensures the most profitable use of that resource. It can also help to find the most profitable combination of enterprises.

Time is a farmer's most limited resource. Land can be rented, money can be borrowed and labor can be hired, but there are only 24 hours in a day. Good managers understand that the time they spend on a decision is subject to diminishing marginal returns. That is, the added probability of making a good decision increases with the amount of time spent gathering information and analyzing the decision, but there comes a point where more time spent on a decision won't increase the certainty of making the right decision. Good managers allocate their time so that the time spent and the expected payoffs from each decision are about the same.

3.0 TIME VALUE OF $

Many inputs, such as fertilizer and chemicals, are used as they are purchased, so evaluating their costs and returns is straightforward. However, evaluating returns from equipment that can last for several years is complicated because the costs and returns don't occur in the same year. The problem is in comparing the value of a dollar today with a dollar in the future. This involves the time value of money.

The central point to the time value of money is that a dollar today is worth more than a dollar tomorrow. The reason for this difference in value is that people normally would rather consume a good today than wait to consume it in the future, everything else being equal. Because of this preference to consume good now, people have to be paid to defer consumption to the future. If you put a dollar in savings account for a year, the bank will return your dollar plus interest at the end of that year. Interest earned on savings, in effect, is payment for deferred consumption.

Interest gives two aspects to the time value of money – compounding and discounting. Compounding means earning interest on an investment and reinvesting the interest earned back into the investment. One hundred dollars invested at 8% would be worth $125.97 at the end of three years (i.e., $100 x 1.08 x 1.08 x 1.08). Discounting is the flip side of compounding. The present value of $125.97 to be paid to you in three years discounted at 8% is $100 (i.e., $125.97/[1.08 x 1.08 x 1.08]). When we compare the costs and returns to investments over time, we often discount the costs and returns to the present and add them together to measure the **net present value**.

To illustrate using net present value, consider the following example. A farmer buys a calf to background on pasture for a year and then feed for a year to sell as a finished animal. Assume that the calf costs $400 and requires an additional $100 in feed the first year, or $500 in start-up costs, and $300 worth the feed the second year. The finished animal can be sold for $950 at the end of the second year.

Is this a good investment? The answer depends on the time value of money and the rate of discount. If the farmer borrows from the bank to finance buying and feeding the calf, the interest rate charged by the bank should be considered the discount rate. If the farmer uses his or her own money to buy and feed the calf, the discount rate should be the opportunity cost of the money, or what he or she could earn from leaving the money in some other investment.

Table 3 reports the present value of net returns for the above example. If there is no time value to the money (i.e., a "0" discount rate), then the project will yield a $150 net return. At a discount rate (or cost of money) of 8%, the project would yield a net return of $36. And with a discount rate of 11%, the project just breaks even.

Table 3. Present Value of Returns under Different Discount Rates

			Present Value of Net Returns		
Year	Costs	Returns	Not Discounted	Discounted at 8%	Discounted at 11%
Start up	500		-500	-500	-500
Start of year 2	300		-300	-278	-270
End of year 2		950	+950	+814	+771
			150	36	1

A business decision that has costs and returns occurring over time involves more than just adding up the costs and returns in one year. Both the costs and returns need to be discounted to take into account the time value of money. The discount rate should also be considered. In general, the higher the discount rate, the lower the net present value of a future return.

4.0 COSTS OF PRODUCTION

4.1 Opportunity Costs …

Not all resources that a farmer uses are purchased inputs, with costs determined in the market place. Some inputs, such as own land, fully paid for equipment and the farmer's own labor and management expertise, do not have a cash cost. Nevertheless, these inputs do have a cost associated with their use and they should not be treated as free resources. In each case, these resources have value in their current use as well as in alternative uses. The highest value in alternative uses is called the opportunity cost of the resource. For example, the opportunity cost of the farmer's time is what the farmer could receive in wages or salary by working for someone else. The opportunity cost of land is the income that could have been received if the land had been put to a different use. Opportunity costs are not direct, out-of-pocket costs, but they are still real costs in terms of what would be lost if the resources were not used effectively. Profits are maximized when the returns to the resource exceeds its opportunity costs; in other words, when the resource is earning more in its current use than in any other opportunity use.

At times farmers tend to treat their own resources as if they were free. They figure if they already own the resource that there is no cost in using or not using the resource. Their own labor and management expertise is especially overlooked. But all resources have real costs, even if it is only an opportunity cost. Overlooking the opportunity cost of a resource allows for the misallocation of that resource. The ultimate opportunity cost is what the farmer could receive by selling out and investing the money elsewhere.

4.2 A further word on costs

Every time a farmer drives a tractor across a field, two types of costs are incurred. Understanding the difference between these costs will help you to evaluate the benefits and costs of precision agriculture for your operation.

4.3 Operating costs are …

Operating costs are the cash costs or out-of-pocket expenses of running the tractor. These costs are primarily fuel and lubrication, repairs and maintenence and labor costs (wages and benefits for the time operating, setting-up and taking-down).

4.4 Ownership costs are …

Ownership costs are incurred whether the tractor is running or sitting in a shed. There are five of these costs:

Depreciation
Interest
Taxes
Insurance
Housing.

Depreciation is that portion of the tractor you use up in one year. Suppose you buy a $100,000 tractor that has an expected effective life of 10 years. If you use the tractor for 10 years, the cost of the tractor is spread out over those 10 years. In effect, you use 1/10th of the tractor each year, or the tractor can be considered to depreciate by $10,000/year. (For tax reasons you usually want to depreciate equipment and machinery as quickly as possible.)

Interest is the cost to borrow the money to buy the tractor, or the opportunity cost of your money if you use your own savings.

Taxes, insurance and housing are usually a small percentage (2-5%) of the purchase price, but they do add to the cost of owning the tractor.

Insurance and housing combined usually amount to no more than about 2-3% of the value of equipment. However, they should be added as a real cost when one considers a new piece of equipment or machinery.

Precision agriculture systems often involve new and specialized equipment. When comparing the costs and returns from PA, it is important to not confuse the purchase price of the equipment with the annualized ownership cost of the PA equipment. A $10,000 system with a three-year expected lifetime may have ownership costs of $4,000/year. You would be over estimating the system's costs, and subsequently under estimating the system's annual net returns, if you used the $10,000 purchase price rather than the $4,000 annual ownership cost.

5.0 RISK AND UNCERTAINTY

Farming is a risky business. There are risks that the crop will become diseased, prices will fall, and foreign competition will push you out of business. An additional risk is that the new technology you just purchased in installed will not perform up to expectations, or that the company you bought it from will go bankrupt, leaving you without technical support. The following discussion of risk and uncertainty is presented to provide a framework for evaluating the risks associated precision agriculture.

Every time you roll an unweighted, six-sided die, you face a 1/6 probability of rolling a 1, or a 2, or a … 6. Suppose you receive a payoff, say $1, if you roll a 6. Mathematically, the expect value of the game is:

$$\$1 * \text{Prob}[1/6] = \$0.167.$$

In words: if you roll the die a lot of times, you would expect to receive the $1 payoff once out every six rolls. On average, for each roll you would receive $0.167. Or, your expected payoff is $0.167.

Now suppose it cost you $0.25 to play the described game. You can use economics to frame your decision; i.e., is the return greater than the cost?

$$\$1*\text{Prob}[1/6] = \$0.167 < \$0.25$$

In this case the cost ($0.25) is greater than expected return ($0.167). If your goal is to maximize your return, you would not play the game.

What if the game cost only $0.10? In that case, the return would be greater than the cost, and you would likely play the game.

{What about people who gamble? Why are casinos spreading across the country even though most people know the odds of winning are against them? Think back to utility. Some people enjoy the thrill of gambling – the unknown of winning or losing. People gamble to maximizing their utility – the satisfaction from the act of gambling – rather than from any real hope of making a positive return.}

Farmers play risky games every time they plant a crop. There is a probability that the yield will be an expected amount. Often times there is a probability associated with the price as well. The cost of the crop is known (or should be if the farmer keeps good records). Hence, the farmer can expect profit from a crop to be:

Profit = Price * Prob[yield] – cost.

Farmers with several years experience have a pretty good idea of the yield they can expect for a given crop on a specific field. Of course, some years' yields will be less than what they expected and other years above expectations. That is the nature of a risky enterprise such as farming.

New farmers can get an idea of the probability of having a below average, average, or above average yield from government or private crop advisors, who rely on information from a variety of source to predict how a crop will do in a specific site.

Suppose you were planting a new crop and had little or no idea of what to expect? Economists would say that you are facing an "uncertain" situation. Profits are indeterminate when

Profit = Price * Prob[unknown] – cost.

Most farmers prefer a risky situation to an uncertain situation. There are ways to deal with risk (take more Agribusiness to find out how), but one faces the unknown with uncertainty.

6.0 VALUE OF INFORMATION

Precision agriculture has been defined as information technology applied to agriculture. Information has been input in production for years. For example, farmers would know which fields were most productive, what would grow best in which field. Dairy farmers knew which cows would produce more milk if fed more, and which cows would just put on more weight. This intimate knowledge of the production process works well when fields are relatively small and a commercial herd has a score of cows. However, when production decision are made for fields that encompass a section and herds have thousands of cows, intimate knowledge has to be replaced by systematic information in order to have effective decisions made. Information as an input has unique characteristics.

First of all, data is not information. Data has to be screen and edited into a form which provides information. For example, 22 is data but provides no information. Knowing the temperature in Toronto, Canada, is 22*C provides a context for the data, but still provides little information unless you know that 22*C is about 72*F.

Information has value when it affects actions or prior beliefs. If you are thinking of visiting Toronto, then knowing that the expected temperature will be 22*C when you are thinking of visiting is valuable information. Further, having a reference point for 22*C, i.e., most Americans know that 72*F is comfortable, may affect your decision to visit Toronto, or re-affirm your prior belief that Toronto would be a nice place to visit in the summer.

The value of information increases with timeliness, accuracy, and lack of bias. If you have planned a business trip to Toronto in two days, knowing what the temperature will be in two days has more value to you than knowing what the temperature was two weeks ago. A forecast of 22*C is more accurate than a forecast of "in the 20's". Lastly, you may expect more positive bias from the Toronto Chamber of Commerce than from Weather Canada (e.g., "warm and comfortable" as opposed to "expected high of 22*C".)

7.0 THE YIELD GAP

All crops have a maximum potential yield, based on the genetic potential of the plant. Livestock have a similar potential genetic yield; e.g., the maximum yield of milk, eggs or meat from a given animal. This maximum is rarely achieved. The reason why can be as obvious as a disease or an insect infestation, or as hard to determine as the lack of water or nutrients at a critical stage of development. The difference between the maximum possible yield and the actual yield can be called the "yield gap". An example of a yield gap is illustrated in Figure 2.

Figure 2 measures the growth of a plant on the vertical axis and time on the horizontal axis. If the plant has received the optimum amount of water and nutrients when required and was not damaged by any pests or other infestations, then yield will be at the maximum genetic potential Y_{max}. However, agriculture is rarely perfect. Most likely, the plant will be damaged by

- less than the optimum amount of water
- less than the optimum soil nutrients
- an insect or weed infestation
- a fungus or other pest infestation.

The yield from a damaged plant, Y_{damage}, is less than Y_{max}. The difference between the two can be called the yield gap. The greater the yield gap, the more the damage costs the farmer in terms lower yield and hence lower revenue.

Suppose the crop becomes infested with a blight at time "s". If the farmer does not learn about the blight, he could lose the entire crop. However, suppose the farmer learns about the blight and is able to control the damage. Damage has occurred, but if further damage can be controlled, then the yield will be $Y_{damaged}$, which is less than Y_{max} but better than no crop at all.

The earlier that a farmer knows about damage happening and is able to control the damage, the less the yield gap will be. Mathematically this can expressed as

$$Y = Y_{\max} - \int_{s}^{t} D(t) C_t$$

where Y is actual yield, Y_{max} is the maximum potential yield, D(t) is damage occurring over the time period “s” to “t”, and C_t is action to control the damage at time “t”. If action to control the damage is taken quickly, i.e., at the limit s = t, then damage is minimized. However, the longer it takes for the farmer to take action to control the damage, the greater the damage and the larger the yield gap.

8.0 PARTIAL BUDGETING

The simple economics of a new technology is that if the returns from using the new technology are greater than the costs of the new technology, then use it. Otherwise, don’t. The difficult part is that new technology is often very complex to implement, and determining costs and returns for a new system is rarely simple.

8.1 **Partial Budgeting is …**

Partial budgeting is a method for comparing the costs and returns from a proposed change in a farm business. It is especially useful for evaluating a specific, limited change with what is currently being done. For example, a partial budget would be a good way to evaluate the costs and returns of a new combine. Suppose the new combine costs less to operate than the current combine, and is expected to harvest three more bushels of corn/acre due to less loss. The partial budget provides a consistent framework for comparing the lower operating costs and increased revenues from the new combine to the cost of buying the combine.

Both a strength and a weakness of partial budgeting is that it is limited to two alternatives. This means that partial budgeting is not a good way to determine which of three crops is the best one to grow, but a partial budget is an excellent way to evaluate whether a new technique or piece of equipment will benefit your operation.

To use a partial budget to evaluate a proposed change requires that you are able to answer four questions about that change:

1. What new or additional costs will be incurred?
2. What current costs will be reduced or eliminated?
3. What new or additional revenue will be received/
4. What current revenue will be reduced or lost? (Kay and Edwards, p. 183)

The answers to these questions are arranged in the following format:

8.2 The Partial Budget Format

<table>
<tr><td colspan="2">Problem:</td></tr>
<tr><td>Reduced Revenues</td><td>Additional Revenues</td></tr>
<tr><td>Additional Costs</td><td>Reduced Costs</td></tr>
<tr><td>Total Costs
(Additional Costs +
Reduced Revenues) $ ________</td><td>Total Benefits
(Additional revenues +
Reduced Costs) $ _________</td></tr>
<tr><td colspan="2">Net change in profits (B – A): $ _________________

Benefit/Cost Ratio: B/A = ____________</td></tr>
</table>

The Problem refers to the decision being evaluated, such as buy a new combine or keep the current one.

Additional Costs are those costs that will be incurred with the new technique, method or enterprise. Recall that new equipment usually has two types of costs: operating costs and ownership costs. Both are important factors in accurately determining the profitability of an alternative.

Reduced Revues are current revenues that will be lost or reduced should the new alternative be adopted. Not all alternatives will have reduced revenues.

Additional Revenues are those that will be received only if the new alternative is adopted. As with Reduced Revenues, not all alternatives will have Additional Revenues.

Reduced Costs are those now being incurred that would longer be incurred if the new alternative is adopted. As with Additional Costs, both operating and ownership costs need to be considered. For example, replacing an old combine with a new combine means that both the operating and ownership costs incurred from the old combine will be eliminated.

Costs: the Additional Costs and Reduced Revenues are the costs of the new alternative. These can be considered the detriments of the new alternative.

Benefits: the Additional Revenue and the Reduced Costs are the benefits of the new alternative.

Net Benefits: if the Benefits are greater than the Costs, the new alternative has positive net benefits. Any alternative with negative Net Benefits should not be considered, as it will cost more than it will return.

Benefit/Cost Ratio: looks at the relative values of the benefits and costs. An example can best explain why this ratio is important. Suppose you are evaluating two alternatives. Alternative A has $100,000 of Total Benefits and $99,000 of Total Costs. Alternative B has $10,000 of Total Benefits and $9,000 of Total Costs. Both alternatives have Net Benefits of $1000, which at first glance may look profitable. However, the Benefit/Cost Ratio of Alternative A is 1.01, which means that the alternative is expected to return $0.01 for every $1.00 spent on the alternative, or a 1% return on expenditures, while Alternative B has a Benefit/Cost Ratio of 1.10. Even though the Net Benefits are the same, the B/C Ratio shows that the return from Alternative B is much better. Both Net Benefits and the Benefit/Cost Ratio should be used to evaluate the results from a partial budget.

8.3 Partial Budgeting: an example

Marcie is trying to decide whether to purchase a combine or to continue to have her 1000 acres of wheat custom harvested. She currently pays $18.50/acre for custom harvesting. She estimates the costs of the new combine would be:

Ownership costs:	taxes	$50
	Depreciation	5,000
	Interest	6,000
	Insurance	100
	Total ownership costs	$11,150
Operating costs/acre:	repairs	$2.40
	Fuel & oil	1.20
	Labor	0.50
	Total operating costs/acre	$4.10

A neighbor who is not pleased with his custom harvesting operator told Marcie that he would pay her $19.00/acre to harvest his 500 wheat.

<table>
<tr><td colspan="2">Problem: Buy a new combine or continue with custom harvesting.</td></tr>
<tr><td>Reduced Revenues
None</td><td>Additional Revenues
Custom harvest for neighbor
$19.00 x 500 acres $ 9,500</td></tr>
<tr><td>Additional Costs
Ownership costs $ 11,150
Operating costs
($4.10 x 1500 acres) 6,150</td><td>Reduced Costs
Custom harvest
$18.50 x 1000 acres $18,500</td></tr>
<tr><td>A. Total Costs
(Additional Costs +
Reduced Revenues) $ 17,300</td><td>B. Total Benefits
(Additional revenues +
Reduced Costs) $ 28,000</td></tr>
<tr><td colspan="2">Net change in profits (B – A): $ 28,000 – 17,300 = $10,700

Benefit/Cost Ratio: B/A = 1.62</td></tr>
</table>

In the example above, Additional Costs will be the cost of owning the new combine, plus the expected costs of operating it on 1,500 acres (Marcie's 1000 plus the neighbor's 500). There won't be any Reduced Revenues associated with the new combine, but there will be Additional Revenues from custom harvesting the neighbor's 500 acres. Lastly, Reduced Costs will be the $18.50/acre that Marcie will not pay the custom operator if she buys the new combine.

Buying the new combine looks like a good idea for Marcie. The combine is expected to return $10,700 more than it costs, or 62% on each dollar spent.

Note that the costs and returns for the new combine, the new alternative in this example, are expected. Current costs may be known, but the additional costs and returns from a new alternative are at best forecasted or predicted. It is difficult to know with certainty exactly what they will be. This lack of certainty is even more pronounced with new and untried technologies, such as PA.

9.0 PREVIOUS ECONOMIC STUDIES OF PRECISION AGRICULTURE

What do previous studies say about the economics of PA? The results are mixed. Unlike some new technologies, there is no clear answer as to whether or not PA is economical beneficial. While some studies have reported positive returns to variable-rate technology (VRT), others have reported costs higher than returns or no significant difference in returns.

Most previous studies conclude that the economics of PA depend on 1) the system being evaluated and 2) the farm or operation for which the PA system is being evaluated. In other words, some PA system will be economical on some farms, but by no means will all PA systems be economical on all farmers.

The following are some of the factors that appear to affect the overall feasibility of PA

- PA is a system, not a single piece of equipment or technology. A GPS by it self has little value to farmer. However, when combined with a yield monitor or a VRT, it may have value.
- Returns may be positive if costs can be spread over many applications. Specialized equipment, which has limited uses, has greater risks associated with it than equipment that has many uses. A multi-use tractor will likely pay for itself sooner than a new, single-use machine.
- Precision agriculture may not return on low-valued commodities as it does on high-valued specialty crops. Increasing yield by 5% through VRT may translate into $20/acre more revenue on a corn crop but $200/acre on wine grapes. The increased grape yield is more likely to pay for the PA system than the increased corn.
- GPS controlled tractor guidance systems may affect when and how tractors are operated.

10.0 EXAMPLES OF ECONOMIC ANALYSIS OF PRECISION AGRICULTURE SYSTEMS

10.1 Case 1. Evaluating Variable Rate Application

This case will evaluate the economics of variable rate application (VRA) of nitrogen fertilizer. In reality, soils can be tested for up to fourteen nutrients and some VRA systems can apply up to seven nutrients in one pass. However, only one nutrient is evaluated in this case in order to explain the evaluation process.

Suppose you have a field that has two distinct types of soils. The Low Yield soil can produce a maximum of 150 bushels of corn per acre, while the High Yield soil can produce 200 bushels of corn per acre. The Low Yield field can manage up to 200 pounds of nitrogen per acre. Applying more than 200 pounds will not affect the yield, up to some point. The High Yield field can utilize up to 250 pounds of nitrogen per acre. Again, applying more will not affect the yield, up to some point, but applying less lowers the yield. The field is approximately 50/50 High/Low Yield soils.

We will use Partial Budgets to evaluate four different scenarios.

Scenario 1: If you take only one soil sample in this field, you have a 50%/50% chance of testing the Low Yield or High Yield type of soil. If your test sample happens to be from a Low Yield area, you apply 200 pounds of nitrogen per acre, which is the “right” amount of nitrogen on the Low Yield area and not enough on the High Yield area.

Type of Soil	Max. Potential Yield (bu)	Fertilizer Required (pounds)	Fertilizer Applied	Actual Yield	Yield “Lost”	Fertilizer “Lost”
Low Yield	150	200	200	150	0	0
High Yield	200	250	200	150	50	0

Scenario 2: You take only one soil sample, which happens to be from a High Yield area. You apply 250 pounds of nitrogen per acre, which is “right” for the High Yield area and too much for the Low Yield area.

Type of Soil	Max. Potential Yield (bu)	Fertilizer Required (pounds)	Fertilizer Applied	Actual Yield	Yield “Lost”	Fertilizer “Lost”
Low Yield	150	200	250	150	0	50
High Yield	200	250	250	200	0	0

Scenario 3: You take two soil samples, one from a Low Yield area and one from a High Yield area and decide to average them. Hence, “on average” you should apply 225 pounds of nitrogen per acre, which is too much for the Low Yield area and not enough for the High Yield area.

Type of Soil	Max. Potential Yield (bu)	Fertilizer Required (pounds)	Fertilizer Applied (pounds)	Actual Yield (bu)	Yield “Lost” (bu)	Fertilizer “Lost” (pounds)
Low Yield	150	200	225	150	0	25
High Yield	200	250	225	175	25	0

Scenario 4: You take enough soil samples to determine which parts of your field are Low Yield areas and which are High Yield area and use VRT to apply the appropriate amount of nitrogen to each part of your field.

Type of Soil	Max. Potential Yield (bu)	Fertilizer Required (pounds)	Fertilizer Applied	Actual Yield	Yield “Lost”	Fertilizer “Lost”
Low Yield	150	200	200	150	0	0
High Yield	200	250	250	200	0	0

If you were concerned only with maximizing your yields, then you would of course prefer Scenario 4, where you take enough soil samples to determine the optimum amount of fertilizer for each area of your field, and then apply that amount. However, you are more likely concerned with maximizing your profits. As such, you want to determine if the added returns from more soil samples and VRT are greater than their costs.

We will use a Partial Budget to evaluate the economics of the four Scenarios above. Recall the format of a Partial Budget:

Problem:	
Reduced Revenues	**Additional Revenues**
Additional Costs	**Reduced Costs**
Total Costs **(Additional Costs +** **Reduced Revenues) $ ________**	**Total Benefits** **(Additional revenues +** **Reduced Costs) $ __________**

Before we can do a Partial Budget, more information is needed. Assume the following prices and costs:

	Cost	Annualized Cost*
Price of corn	$ 3.00/bushel	n/a
Price of nitrogen	0.25/pound	n/a
Cost of soil sampling	$18.00/acre (1-acre grid)	$ 7.24
	6.00/acre (5-acre grid)	2.41
Variable Rate Technology System		
Ownership Costs		
Global Positioning System (GPS)	$1,500 - 3,000	$600-1,200
Variable rate applicator	3,000 - 5,000	1,200 – 2,010
Operating Costs (labor, fuel & lube)	$ 7.50/acre	

- The annualized cost assumes
  a) the soil sample is valid for three years,
  b) the VRT system has a useful life of three years, and
  c) the discount rate is 10%.

Annualized Cost = Cost* $\{.10/[1 - (1.10)^{-3}]\}$

See: Bohlhje, p. 143-144.

The last piece of information required to evaluate the Scenarios is the size of the corn field. The annualized cost of the VRT system is the ownership cost, not the operating cost. The ownership cost decreases as the number of acres over which to spread those costs increases. For example:

Size of Field	Annualized Cost	Cost per Acre
100	$1,200	$12.00
500	1,200	2.40
1000	1,200	1.20

Partial Budget – Scenario #1 to #4
Assume a 1000 acre field, 5-acre grid sampling, and mid-range GPS and VRA equipment. Note that the GPS and VRA costs are the annualized costs on a per acre basis. The cost of spreading fertilizer at a uniform rate and VRA are approximately the same. Therefore, only the ownership costs and not the operating costs of the VRT enter the Partial Budget.

Problem: Use VRT	
Reduced Revenues $0	**Additional Revenues** 50 bu corn x $3/bu = $150
Additional Costs 25 lbs N x $0.25/lb = $ 12.50 soil sample 2.41 VRT: Ownership: GPS 0.90 VRA 1.61 Operating 7.50	**Reduced Costs** **$0**
Total Costs **(Additional Costs +** **Reduced Revenues) $ 24.92**	**Total Benefits** **(Additional revenues +** **Reduced Costs) $150.00**
Net Benefit: $150 – 24.92 = $125.08	**B/C Ratio: 6.0**

In Scenario #1 you were using less than the optimum amount of fertilizer. By soil sampling you learned that you could apply more fertilizer on part of your field, and that doing so increases yield by 50 bushels or $150/acre. It is clear that the

Partial Budget – Scenario #2 - #4
Same assumptions as before.

Problem: Use VRT	
Reduced Revenues $0	**Additional Revenues** $0

Additional Costs soil sample $ 2.41 Ownership: GPS 0.90 VRA 1.61 Operating 7.50	**Reduced Costs** 50 pounds x $0.25 $ 12.50
Total Costs **(Additional Costs +** **Reduced Revenues) $ 12.42**	**Total Benefits** **(Additional revenues +** **Reduced Costs) $ 12.50**
Net Benefit: $12.50 – 12.42 = $ 0.08	**B/C Ratio: 1.0**

Partial Budget – Scenario #3 - #4
Same assumptions as before.

Problem: Use VRT	
Reduced Revenues $0	**Additional Revenues** 25 bu. x $3/bu = $ 75.00
Additional Costs soil sample $ 2.41 Ownership: GPS 0.90 VRA 1.61 Operating 7.50	**Reduced Costs** 25 pounds x $0.25 $ 6.25
Total Costs **(Additional Costs +** **Reduced Revenues) $ 12.42**	**Total Benefits** **(Additional revenues +** **Reduced Costs) $ 81.25**
Net Benefit: $ 81.25 – 12.42 = $68.83	**B/C Ratio: 6.5**

Notes to the Partial Budgets:

1. The Partial Budgets are on a per acre basis. If the field were smaller, say 500 acres instead of 1000 as in the example, the VRT ownership costs would double.
2. The Net Benefits are significant when the VRT increases yields, but not when the VRT only lowers fertilizer use with affecting yield.

3. There is difficult to know with certainty before hand if you are in Scenario 1 (applying not enough fertilizer on part of your field) or Scenario 2 (applying too much fertilizer).

4. Determining which parts of the field are Low Yield and which are High Yield can be difficult, but there are a number of indicators you can use. Soil maps, yield maps and soil samples on grids can all be used to segment the field.

10.2 Case 2. Grid-sampling vs. Representative Sampling

Suppose you have a map of a field that has clearly defined areas, as shown in Figure 3. Knowing that there are two distinct areas in your field is data. Your job as a manager is to edit and screen that data into information that affects your actions or prior beliefs, and hence has value. How you transform that data into information is in part dependent on how you obtained the data. Four situations about how Figure 3 was obtained are presented below.

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#1. Soil samples done on a 1-5 acre grid.

If the two areas are distinct soil types that respond to fertilizer differently and have different yields, then the data from the soil samples can be used for VRA. Your decision framework is similar to the Partial Budget example previously presented; i.e., will the expected returns be greater than the expected costs?

Soil samples are thought to be accurate for about three years. After that time, the soil should be sampled again to monitor any changes in nutrient requirements. Your decision is whether you should repeat your soil samples on a 5-acre grid, or reduce your costs by taking only two or three samples from the representative areas? The trade off is between the reduced costs of taking representative samples versus the reduced accuracy of representative samples. For a 1000 acre field, the comparable costs are

Method	Costs	
5-acre grid	$6/acre x 1,000 acres	= $6,000
Representative samples	$18/sample x 3 samples	= 54

The savings are large, but there is a risk with representative samples in that you will not know if the reduced accuracy affects yields until after harvest. Given the magnitude of savings and the possible loss from a wrong decision, additional data and information may be helpful

#2. A yield monitor linked to a GPS unit record areas of different yields.

Having different yields in two distinctly different areas is a clear indication that the field can benefit from VRT rather than uniform treatment, but knowing that areas A and B have different yields does not say why the differences exist. Data from a yield monitor along with a soil map is a strong indication that the field has two types of soils and that VRA of nutrients is appropriate. However, without the soils map, the difference in yields could be due to a number of factors. Even with a soils map, it is possible that the difference in yield is due more to soil tilth and moisture retention characteristics than to nutrients.

#3. Veris system identified areas of different electrical conductivity.

Electrical conductivity (EC) can be an indicator of a soil's water retention characteristics. If the difference in yields in areas A and B is due to water retention, then tests of EC may be an inexpensive way to obtain more data and hence more information about how to best manage the field.

#4. A near-infrared aerial photograph identifies areas of distinctly different foliage.

Remote sensing in the form of a picture is data on the field. A physical investigation is required to transform that data into information about why the different foliage is there. Given the information as to the cause, the manager then may be able to do something to minimize damage.

The remote sensing by itself does not provide information nor provide value, but if the remote sensing provides data for the early detection of problems, it can minimize loss from damage. For example, Figure 4 represents an aerial photograph of a large tomato field. Areas A, B and C depict areas of late blight. If detected early, it is possible treat for blight, but a bad case of blight can wipe out a crop.

It is possible that areas A and B could be identified from a bordering road and treated before too much damage is done. If the blight for some reason starts in Area C, is possible for a considerable damage to occur before the manager notices the problem. As discussed in the Loss Function Section, the earlier damage to a crop is detected and treated, the lower the loss due to the damage. Remote sensing is a method to increase the identification of damage and hence lower losses.

The economics of remote sensing and early detection of damage is difficult. The framework is simple:

> If the value of the crop x probability of loss > cost of detection,
>
> Then detection is economical.

It is similar to insurance: there is a small probability of a large loss, the expected value of which is larger than the premium charged. Some years there will be no indication of damage, hence no action needs to be taken. In those years the remote sensing has no value. Other years, however, the remote sensing will indicate damage in a timely manner, action will be taken to mitigate the damage, and the remote sensing had value by minimizing a potentially large loss.

11.0 ENDING COMMENTS

Precision agriculture is the application of information technology to production agriculture. It consists of several complementary components; it is systems that provide data. The economics of these systems depends upon the situation. Farm managers have to determine if a PA system will be economical for their specific, unique operation. However, in certain operations, PA is likely to be economical:

1. Larger operations, where the ownership costs can be spread over more acres.
2. High valued crops compared to lower valued commodities.
3. Intensively managed operations, with a high degree of planning, monitoring and control already in place.
4.

12.0 SERENDIPITIES

Serendipities are unexpected benefits from some action or discovery. A classic serendipity was the development of the light emitting diode (LEM). To showcase the LEM, Texas Instruments threw together hand-held calculators for a trade show. The purpose was to demonstrate the LEM; the calculator was an after thought. The rest is history.

Many benefits from PA will be serendipitous discoveries. The engineers will develop a technology with one purpose in mind, and an enterprising farmer will discover a much better use, in terms of economic benefits. Yield monitors are one such example. A yield monitor with GPS was developed to provide detailed maps of variation in yield across a field. An unexpected benefit is that farmers with yield monitors now know within a pound how much they have loaded onto a truck. Both grain and tomato growers in California have reported virtually eliminating the probability of being stopped for an overloaded truck because of their yield monitors. Some farmers have been buying yield monitors without GPS, strictly to have accurate measures of their truck loads.

There are likely other serendipities occurring. If you come across examples, please send them in to
Whhoward@CalPoly.edu.

13.0 READINGS

The following list of readings on farm management and the economics of precision agriculture may help you to determine if a PA application will be economical on your operation.

13.1 FARM MANAGEMENT TEXTS

Boehlje, M. E. and V. R. Eidman. Farm Management. New York: John Wiley & Sons, 1984. (Chapters 3 & 4 can help with figuring the ownership and operating cost of PA systems.)

Kay, R. D. and W. M. Edwards. Farm Management: Planning, Control, and Implementation. 4th ed. McGraw-Hill Book Company, 1999 (Chapters 11 on Partial Budgeting, Chapter 15 on Managing Risk and Uncertainty and Chapter 17 on Investment Analysis may be especially helpful.)

13.2 ECONOMICS OF PRECISION AGRICULTURE

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Cox, Graeme, Harry Harris and David Cox. “Application of Precision Agriculture to Sugar Cane.” .” In Precision Agriculture: Proceedings of the 4th International Conference, Part A, St. Paul, MN, July 1998, pp. 753-763.

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Yang, C., G.L. Anderson, J. H. King, Jr., and E. K. Chandler. “Comparison of Uniform and Variable Rate Fertilization Strategies Using gird Soil Sampling, Variable Rate Technology, and Yield Monitoring.” .” In Precision Agriculture: Proceedings of the 4th International Conference, Part A, St. Paul, MN, July 1998, pp.675-686.

Swinton, Scott M. and Kezelee Q. Jones. “From Data to Information: The Value of Sampling vs. Sensing Soil Data.” Staff Paper 98-15, Department of Agricultural Economics, Michigan State University, June 1998.