Precision Agriculture Profitability Review*

by

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PRECISION AGRICULTURE PROFITABILITY REVIEW
EXECUTIVE SUMMARY

Site-specific management is intuitively appealing to many producers and agribusiness people, but intuitively appealing ideas are not always profitable. The objective of this report is to summarize and organize the publicly available studies of the profitability of precision agriculture.

Sources were refereed articles from scientific journals or proceedings (86%), and non-technical or non-refereed magazines and monographs specializing in agribusiness services (14%). Scientific, refereed journals were categorized as reports that employed the scientific method to answer research questions (67%), or those that described general aspects of PA (33%). The research questions included both the potential profitability and the adoption process of PA within the agricultural community, including dealerships and producers. Popular magazines comprised 75% of the non-scientific materials reviewed. The remaining 25% of non-scientific materials included documents that described PA generalities.

Of the 108 studies that reported economic figures, 63% indicated positive net returns for a given PA technology, while 11% indicated negative returns (Table 5). There were 27 articles indicating mixed results (26%).

For all PA technology combinations identified, over 50% of the studies reported positive benefits, except for VRT-yield monitor systems (Table 5). About 60% of the studies of N or NPK VRT systems reported profits.

Of the 63 documents reporting benefits authored by economists, 73% reported positive benefits from PA, 16% reported mixed results and 11% negative results (Table 6). Of the nine documents with agribusiness authors reporting benefits, two-thirds (66%) of these articles reported positive results from PA, while two articles (22%) reported mixed results. Only one individual employed by the agri-business sector reported negative returns. In terms of positive benefits, economists and agribusiness authors seem to be coming to be coming to the same conclusions.

The percentage of documents showing positive results was only slightly lower for studies using field trial data, than for those which used response functions or simulation to estimate yield (Table 6). Positive results were reported for 60% of response functions studies, 67% of field trial studies and 75% of crop growth simulation studies.

Unsubstantiated studies showed about the same percentage of positive results as those using partial budgets (Table 6). About 68% of the unsubstantiated studies showed positive results and 64% for the partial budgets.

When all the studies are categorized by crop, corn, soybean and sugar beet studies showed positive profits in over two thirds of cases (Table 7). Only 20% of the studies on wheat showed profits, and in another 20% results were mixed.

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INTRODUCTION

Site-specific management is an old ideal that is intuitively appealing to many producers and agribusiness people, but intuitively appealing ideas are not always profitable. In the push to mechanize agriculture in the 20th century, there was strong economic pressure to use uniform recipes over large areas to maximize returns per worker. Precision agriculture (PA), using computers, sensors and other information technology, potentially allows producers to automate site-specific management for mechanized agriculture. The relatively slow adoption of PA (Lowenberg-DeBoer, 1998; Khanna et al, 1999, Daberkow and McBride, 2000) has raised questions about the farm level benefits of this technology. The objective of this report is to summarize and organize the publicly available studies of the profitability of precision agriculture. The assumption is that any individual study or report might be in error, but the general tendency of a large group of studies should be a reliable indicator.

This study builds on the previous reviews of the economics of precision agriculture by Lowenberg-DeBoer and Swinton, 1997, and Swinton and Lowenberg-DeBoer, 1998. This review includes 58 studies published since 1998. It also extends beyond the soil fertility management focus of the Swinton and Lowenberg-DeBoer studies, to include variable rate plant populations, spatial management of weeds, global positioning systems for equipment guidance and yield monitoring. The report includes a complete reference list and an annotated bibliography that should provide readers enough information to form their own opinions about the profitability results for a specific PA technology.

Sources - Document sources were articles from scientific journals or proceedings (86%), and non-technical, non-refereed magazines and monographs, or the internet specializing in agribusiness services (14%). Scientific, refereed journals were categorized as reports that employed the scientific method to answer research questions (67%), or those that described general aspects of PA (33%). Documents downloaded from Internet sites were classified using the above-mentioned categories. For example, extension publications available over the Internet written by agronomists or agricultural economists were categorized as “scientific.” Documents available from agribusinesses were considered “non-technical” or “non-scientific.” The research questions included both the potential profitability and the adoption process of PA within the agricultural community, including dealerships and producers. This review has attempted to do an exhaustive review of publicly available PA economics studies available in English. Omitted documents or reporting errors should be brought to the attention of the authors of this review.

Popular magazines comprised 75% of the non-scientific materials reviewed. The remaining 25% of non-scientific materials included documents that described PA generalities. Many of the PA testimonials published in the last 8 years have touched on economics. This review makes no claim to an exhaustive review of this non-scientific material.

ANALYSIS

All documents were reviewed to determine whether they reported positive returns to PA and they were classified by a series of variables to help identify trends and clusters. The variables used to classify the studies are given in Table 1. Only descriptive statistics were used. It should be noted that this review accepts the authors' profitability conclusions. It does not attempt to standardize profitability calculation methods, as do Swinton and Lowenberg-DeBoer, 1998.

Table 1. Variables used for literature review summary and analysis.

Variable	Description; entry
Technology	VRT(-N, -P+K, -seed, -irrigation, w/GPS, pH, NPK, yield monitor), soil sensing, none, general PA summary
Crop	Crop Type (corn, soybean, wheat, potato, sugar beet, cotton, barley, rice, oats, none, combinations of these)
Economist?	Economist present as author?; Yes/No
Economic Method	Unsubstantiated Report, Rough Partial Budget, Partial Budget, None
Yield Estimate Method	Response Yield, Field Trial, Simulation, None
Benefit	Yes/No/Mixed
Time Scale	Time until returns are realized; Yes/No
Discount Rate	Yes/No
Fertilizer Cost	Fertilizer cost included as input in budget?; Yes/No
Seed Cost	Seed cost included as input in budget?; Yes/No
Crop Price/Yield	Crop price ($/acre or ha) included in analysis
Crop Input Costs	Additional inputs included (labor, fixed/variable costs); Yes/No
Soil Test Costs	Yes/No
Mapping Costs	Yes/No
Application Cost	Yes/No
VRT/PA Cost	PA/Variable Rate Technology cost included?; Yes/No
Yield Monitor Use Mentioned?	Yes/No
Human Capital Costs	Consultant fees, training, workshops, learning costs; Yes/No
Information Costs	Data management, computer hardware/software, information collection; Yes/No
Useful Life of Equipment	Usefulness of equipment in years; Yes/No
Equipment Costs	Yes/No
Whole Farm Benefits	Yes/No
Environment Mentioned	Yes/No
Land Tenure	Rent, landlord negotiations; Yes/No

(Return to Table Listing.)

DESCRIPTION OF STUDIES

Technology - Variable rate technology (VRT) was the most common PA component in the literature (73%). This figure is somewhat misleading since VRT is used in combination with other technologies commonly associated with PA, such as GPS and GIS, grid soil sampling, and integrated pest management (IPM). Twenty-one percent of the VRT-related reports concerned nitrogen management, followed by VRT-P&K (5%) and VRT-pH (3%). Non-specific VRT reports (23%) reviewed the technology in general, or as a combination of the above technologies. Variable rate seeding (7%) and irrigation (2%) followed VRT fertilizer management strategies in report frequency. Seven percent of the reports dealt with weed management and pest control using VRT. Yield monitors and GPS were reviewed in conjunction with VRT in 5% and 2% of the reports, respectively. Five articles dealt specifically with soil sensing (4%). Twenty-six percent of the reviews summarized the economic benefits of PA technology.

Crops – Fifty-four of the articles reviewed discussed economic returns generated by experiments with or application of PA technology with corn. Wheat (13%), sugar beet (3%), potato (4%), and soybean (3%) followed corn. There were nine reports discussing variable rate technologies applied to corn-soybean rotation systems (9%).

Table 2. Frequency (%) of PA Technologies Reviewed in Documents.

Technology	Percent
VRT*, Nitrogen	21**
VRT, Phosphorous and potassium	5
VRT, Weeds or pests	5
VRT, Seeding	7
VRT, pH	3
VRT, Yield Monitor	5
VRT/GPS Systems	2
VRT, Irrigation	2
VRT, Combination/general	23
Soil Sensing	4
PA technology summaries	26
Total Number of Documents	133

*Variable rate technology.
**Numbers do not sum to 100% because of rounding error.

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Barley was reviewed in 2% of the articles, while oats, cotton-corn and rice-corn rotation systems, cotton, and sorghum were each 1% of the subject crops in the literature reviewed. Thirty-seven entries were recorded as "not applicable" since the subject matter concerned adoption patterns, the current state of PA, or PA in general (28%). A "variable" category (4% of the literature) indicated that the authors were not specific as to which crop was under investigation; for example, the term "grain" may have been used throughout the report.

Economists – Like other branches of science, economics has time-tested methods, usually learned through university level education. Non-economists often add fresh insights based on non-standard methods of analysis. Do economists and non-economists arrive at the same conclusions?

It was not possible to determine the training of all authors. Current employment was taken as a proxy for economic training. It was assumed that those employed by economics organizations (e.g. university economics or agricultural economics departments; USDA Economic Research Service) had substantial training in economic methods. Authors employed by economic or agricultural economic institutions authored 66% of all the material reviewed. Of the 108 documents reporting profitability analyses, individuals employed by economics organizations authored 57%.

Twelve percent of the articles reviewed were written by individuals employed by the agribusiness sector. Ten articles of the articles with agribusiness authorship provided profitability analyses.

The number of studies of precision agriculture with input from economists has grown (Fig. 1). In the early 1990s the only economic evaluation of precision agriculture was in the form of rough profitability estimates that appeared in agronomic studies.

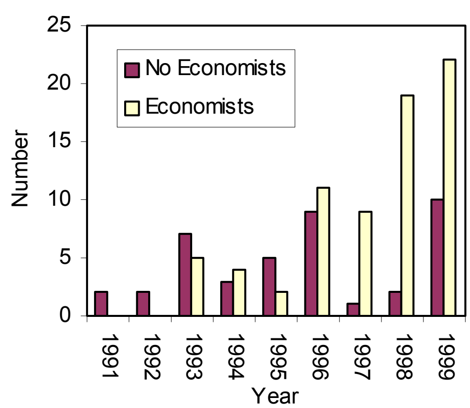

Figure 1. Number of reviewed articles on the economic feasibility of PA technologies co-authored by economists from 1991 to 1999.

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The first studies co-authored by economists appeared in 1993. In 1998 and 1999, over 20 articles or reports on PA appeared annually with authorship by economists.

Economic methods - Three general categories grouped methods used to evaluate the economic feasibility of a practice: unsubstantiated reports, rough partial budgets, and partial budgets. Articles or reports providing lump sum numerical estimates suggesting the profitability or negative returns attributable to a practice without supplying detailed information about changes in costs and revenue were classified as "unsubstantiated reports". The changes in costs sought include:

- input costs (seed, fertilizer, dryer fuel),
- costs of the technology employed (applicator costs),
- information costs and data management,
- computer costs (hardware/software),
- training costs, learning costs (lag time/time lost),
- sinking funds or discount rates, net present value,
- equipment costs and equipment life span (rental rates, sinking fund, depreciation)
- custom service charges/consulting charges
- soil test costs, mapping costs,
- labor costs involved with any of these activities

Reports that mentioned the existence of these details, but failed to enumerate them during analysis, or glossed over input details were labeled as "rough partial budget analysis." Rough partial budget analysis generally provided a table demonstrating the change in costs caused by the addition or practice of a technology component compared to standard operating expenses. For example, variable rate nitrogen application may have been compared with conventional fertilizer treatments. Returns from both practices may have been compared in tabular form, but additional costs incurred by soil testing, lab analysis, and variable rate applicator cost were often not factored, or were taken for granted and buried in the text.

Partial budget analysis documented most or all of the above mentioned costs. Examples of detailed partial budgets are found in Lowenberg-DeBoer and Swinton, 1997, Lowenberg-DeBoer, 1999, and Swinton and Lowenberg-DeBoer, 1998. Some reports implemented dynamic optimization models that incorporated detailed partial budgets (i.e. Isik et al., 1999, Feinerman, Eli, and Eshel Bresler. 1989, Letey, J., H.J. Vaux, and E. Feinerman. 1984 and Schnitkey et al., 1996). Optimization model articles were subsumed under the "partial budget" category. When no numerical economic analysis was provided, but positive returns were attributed to a particular technology, the category "not applicable" was used.

Yield Estimators – Swinton and Lowenberg-DeBoer (1998) hypothesize that the method of yield estimation influences PA economic results. In particular, they find that studies using simulation are more likely to show positive benefits than those based on field trials. This is because simulation models do not include all of the possible production constraints; they usually assume that factors not included in the model are at non-limiting levels.

Three categories were used to define the yield estimators found in the literature: response functions, field trials, and simulation models. In a sense all three of these are methods meant to mimic crop response under alternative agronomic practices. The response functions and crop growth models are digital simulations, while field trials are analog simulations.

Response functions are generally single equations, often quadratic, that estimate the yield of a given crop in relation to a given set of inputs, such as fertilizer, plant population, or lime. Since the inputs are generally economically quantifiable, response functions facilitate comparison between input changes and the cost of making those changes. Response functions are also useful for modeling exercises. About 23% of documents reporting benefits used response functions.

Crop growth models are usually complex multi-equation simulations that attempt to mimic the physiological processes of plants in computer code (for example, see reference Watkins et al., 1998). They are typically built and validated with field trial data. They incorporate growth coefficients and other information from a wide range of scientific studies. About 22% of documents reporting benefit estimates used crop growth simulation.

Field trials are meant to mimic crop response to agronomic practices in farmer's fields, but typically on a smaller area and with more control. They have the advantage of reflecting a broader range of yield limiting factors than the response functions or crop growth simulation. Sometimes questions are raised about how representative of trial sites are, the limited number of weather years, and the great care lavished on trial plots.

The classic small plot trials use plants grown on plots of a few square yards on an experiment station to extrapolate results to crops grown by farmers over thousands of acres. Yield monitors and other PA technology have allowed these experiments to approach farm scale.

Ordinarily agronomic practices follow an experimental design that facilitates comparison between treatments. Usually, that design involves some type of linear additive model created to compare average results between treatments with a statistical technique called "Analysis of Variance." Sometimes those doing field trials claim that they do not use a model. In fact, their results depend on a very specific and highly restrictive model of crop response. About 40% of documents reporting benefits used field trial data.

When no yield estimator was presented (13%), "not applicable" (NA) was entered as a data point. About 13% of the studies falling into the NA category for both the economic methods and yield estimator questions.

Table 3. Economic methods and yield estimators identified in the literature reviewed.

Analysis Methods	Percent
Economic Method	
Partial Budget	50
Rough Partial Budget	19
Unsubstantiated Reports	20
Not Applicable	11
Total Number of Documents	108
Yield Estimator	
Simulation	22
Response Function	23
Field Trial	40
Not Applicable	13
Total Number of Documents	108

(Return to Table Listing.)

Time Scale and Discount Rate - Factors relating to time scale include the period of test validity (soil tests, yield maps), whether costs were spread out over an acres/time period, and the net revenue period (for example, Isik et al., 1999 and Lowenberg-DeBoer et al., 1994). When these details were mentioned in reports they were noted. Twenty-seven percent of the articles reviewed included one or more of these factors in a budget analysis. The general heading "discount rate" refers to any report that included annuity, amortization, sinking funds, or net present value of any production inputs, including PA technologies in budget analyses. Discount rate was included in budget analyses in 35% of the articles.

Input and VRT/PA Costs - Input costs considered in this review were fertilizer costs, seed costs, application costs, and any variable and fixed costs mentioned by the author(s). Variable rate technology and PA costs were considered separately for comparative purposes to verify whether benefits espoused by the author(s) included PA technology costs, other farm input costs, and crop yield. Ninety percent of the reports included farm inputs in budget analyses including budget details, while 81% included PA technology costs.

Human Capital and Information Costs - Conventional economic feasibility studies of PA technology have often failed to include human capital and information costs in budget analyses (see Anonymous, 1996, Lowenberg-DeBoer, 1995, Lowenberg-DeBoer and Boehlje, 1996, Lowenberg-DeBoer, 1997, and Swinton and Lowenberg-DeBoer, 1998 for examples). One article reported a service fee of $25.57/acre, including grid sampling soil test and variable application charges (Thrikawala et al., 1999). Another study reported consultant fees of $0.50/acre (Swinton, S.M., and J. Lowenberg-DeBoer, 1998), which quickly adds up when break-even prices balance on pennies. Table 4 lists the human and information costs either used in budget analyses, or mentioned in reports. In all, 31% of the articles reporting economic benefits included human capital costs.

Under the category "Information costs," an item labeled *information costs** refers to costs associated with grid soil sampling, lab testing, GPS services, or any PA activity that generates useful information used to change a management strategy. When information costs were grouped together, 44% of the reports included or mentioned the role information costs in determining the economic feasibility of PA.

Additional Variables - Other variables considered in the literature review included yield monitor use, PA equipment cost and life span, or environmental issues related to PA. Little to no empirical data exists regarding the environmental impacts of precision agriculture, but 25% of these documents report potential environmental benefits. Likewise, many reports did not explicitly include equipment cost and yield monitor use, and lifespan in their feasibility assessments. Only 29% of all studies reviewed included equipment costs in calculations or even mentioned them. Some 35% of all studies mentioned yield monitor use, and 17% of all studies specified the useful life of equipment in their estimates.

Table 4. Frequency (%) Human Capital and Information Costs were included in economic analyses of PA literature reviewed.

Input Type	Percent
Human Capital	
Labor	24
Labor and learning costs	2
Labor and training costs	1
Labor, workshop, and training costs	2
Human capital costs mentioned, not defined	2
Not mentioned	69
Base	108
Information Costs	
Data management	6
Data management and computer	1
Computer and information costs	6
Information costs*	7
Data management, information costs	2
Data management, computer, and information costs	3
Information costs mentioned	19
Not mentioned	56
Base	108

*Information costs** refers to costs associated with grid soil sampling, lab testing, GPS services, or any PA activity that generates useful information used to change a management strategy.

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REPORTED BENEFITS

Whether authors reported the technology had positive, negative, or mixed returns was recorded. Though this category seems to be objective, it often is not. An objective comparison would require consistent methodology over all studies, similar to the analysis of nine VRT fertilizer studies by Swinton and Lowenberg-DeBoer (1998).

All of the studies reviewed in this section dealt with economic returns, but as noted above calculation of returns differed. A subjective element may enter into the choice of which costs and returns to include. There is also a subjective element in deciding on the criteria for a "positive benefit." Does a positive benefit mean that the overall average return is positive? Does it mean that return is positive in a certain percentage of site years (i.e. 50%)? There is also a question about the time period over which benefits are realized.

Mixed results indicated that although there may have been some positive net returns, the authors did not have enough confidence to support the general assertion that similar results could be achieved under similar circumstances. Oftentimes conclusions in these reports indicated that more research needed to be done in order to reach a valid conclusion.

Negative results have a subjective component as well. Like positive results, reports that concluded a technology (or combination thereof) as applied to a certain crop were not worthwhile was apparent in the numbers and equally apparent in the tone of the narrative. Some treatment results may have generated positive returns, but not enough for the authors to conclude that the investment was economically feasible. However, other reports provided sufficient evidence that a given technology produced *de facto* negative returns for a given crop.

Overall Results - Of the 108 studies that reported economic results, 69% indicated positive net returns for a given PA technology, while 12% indicated negative returns. There were 21 articles indicating mixed results (19%).

Of the 62 documents reporting benefits authored by economists, 73% reported positive benefits from PA, 11% reported mixed results and 16% negative results (Table 6). Of the nine documents with agribusiness authors reporting benefits, two-thirds (66%) of these articles reported positive results from PA, while two articles (22%) reported mixed results. Only one article (11%) written by an individual employed by the agri-business sector reported negative returns. In terms of positive benefits, economists and agribusiness authors seem to be coming to be coming to the same conclusions.

The percentage of documents showing positive results was only slightly lower for studies using field trial data, than for those which used response functions or simulation to estimate yield (Table 6). Positive results were reported for 60% of response functions studies, 67% of field trial studies and 75% of crop growth simulation studies.

Unsubstantiated studies showed about the same percentage of positive results as those using partial budgets (Table 6). About 68% of the unsubstantiated studies showed positive results and 64% for the partial budgets.

When all the studies are categorized by crop, corn, soybean and sugar beet studies showed positive profits in over two thirds of cases (Table 7). Forty-two percent of the studies on wheat showed profits. Of those studies reporting numerical estimates for VRT N, 72% of corn studies and 20% of wheat studies showed profits (Table 8).

Table 5. Summary of reported benefits for PA technology combinations in the literature reviewed.

Technology	Reported Benefit (%)			
	Yes	No	Mixed	Base
VRT-N	63	15	22	27
VRT-P, K	71	29	0	7
VRT-Weeds, Pests	86	14	0	7
VRT-pH	75	0	25	4
VRT-GPS Systems	100	0	0	3
VRT-Irrigation	50	0	50	2
VRT-Seeding	83	17	0	6
VRT-Yield Monitor Systems*	43	14	43	7
VRT-NPK, General	75	8	16	24
Soil Sensing	20	40	40	5
PA Technology Summary	77	0	23	14
PA/VRT Technologies combined	63	11	27	108

*These figures considered reports estimating the benefits of yield monitors in conjunction with VRT, not yield monitors alone.

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The level of returns varies widely by crop and technology (Table 9). The average return to VRT N in sugar beet studies is $74/acre ($48.25, net). Estimated returns to VRT lime on 2.5 acre grids in Indiana varied from $3.46/a to $5.07/a. Reported returns to site-specific fertility management in corn and soybean systems range from losses of over $100/a to gains of $80/a. The reported range of VRT plant populations for corn is $0.97/a to $2.72/a. VRT weed control returns varied depending on weed pressure and patchiness from $0.01/a to $11.67/a. GPS guidance benefits were estimated at about $0.52/a compared to foam markers for the producer who already has a GPS.

Unlike VRT fertilizer or pesticide, yield monitor benefits have been difficult to estimate because they often extend to the whole farm. For example, if a producer uses a yield monitor to identify a good hybrid, that hybrid will be planted on many fields, not just the field on which the hybrid comparison was made. All the yield monitor studies reviewed were rough partial budgets. No study has evaluated yield monitor benefits at the whole farm level. In Table 5, for example, profitability studies considered yield monitors coupled with some form of VRT. As discussed, results from feasibility studies are highly variable and context-specific. It would be expected that studies looking at the combination of VRT and yield monitors would demonstrate mixed results. Recent reports (Farm Industry News, 2000.) have demonstrated returns on investment for yield monitors and guidance systems after a single growing season.

Some PA technologies and crops are notable by their absence. Apparently, there are no publicly available studies of the economics of remote sensing for agriculture. None of the economic studies focused on horticultural or orchard crops.

Table 6. Frequency (%) of reported benefits from PA technology that were positive, negative, or mixed by authorship, yield estimator and economic method.

		Reported Benefits (%)		
		Yes	Mixed	No
Economist?	% Articles authored by Economists (Count)			
Yes	61 (62)**	73	11	16
No	39 (46)	63	13	24
Base	108			
Yield Estimator	% Articles Using Method			
Response Function	23 (25)	60	28	12
Field Trial	39 (43)	67	19	14
Simulation	25 (26)	75	8	17
Not Applicable	13 (14)	79	0	21
Base	108			
Economic Method	% Articles Using Method			
Unsubstantiated	20 (22)	68	27	5
Partial Budget*	69 (74)	64	16	16
None	11 (12)	75	25	0
Base	108			

*Rough partial budgets were combined with partial budgets.
**10% of the authors in this category were affiliated with or employed by the agribusiness sector. Though not formally identified as economists, it is assumed individuals representing agribusiness companies have minimally practical financial and economic experience, if not more advanced academic degrees in a related field.

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Table 7. Reported benefits of PA technology according to crops.

Crop	Benefit (%) from PA Technology			
	Yes	No	Mixed	Cases
Corn	69	15	17	48
Potato	Y* (3)	N* (1)	0	4
Wheat	42	33	25	12
Soybean	Y	.	.	2
Sugar beet	80	20	.	5
Barley	Y	.	.	2
Oats	Y	.	.	1
Corn-cotton	Y	.	.	1
Corn-soybean	89	.	11	9
Corn-rice	Y	.	.	1
Cotton	Y	.	.	1
Sorghum	Y	.	.	1

*Yes/No = reported benefit.

(Return to Table Listing.)

Table 8. Profitability summary of PA technologies and crops where technologies were implemented.[†]

		Reported Benefit (%) from PA Technology			
Technology	Crop	Yes	No	Mixed	Studies
VRT-N	Corn	72	6	22	18
	Potato	.	N	.	1
	Wheat	20	40	40	5
	Soybean	.	.	M	1
	Sugar beet	Y*	.	.	1
	Corn-soybean	Y	.	.	1
VRT-seeding	Corn	83	17	.	6
VRT-Weed/Pests	Corn	Y	.	.	2
	Wheat	Y	N**	.	2
	Soybean	Y	.	.	2
VRT-Irrigation	Corn	Y	.	.	1
	Corn-cotton	.	.	M***	1
VRT-P,K	Corn	60	40	.	5
	Potato	Y	.	.	1
	Corn-soybean	Y	.	.	.
	Wheat	.	.	M	1
VRT-Yield Monitor	Corn	Y	N	M	3
	Sorghum	.	.	M	1
	Cotton	.	.	M	1
VRT-pH	Corn	Y	.	.	2
	Corn-soybean	Y	.	.	1
Soil Sensing	Corn	Y	N	M	3
	Sugar beet	.	N	.	1
	Corn-soybean	Y	.	.	1
VRT-General	Barley	Y	.	.	1
	Corn-soybean	Y	.	.	3
	Corn-rice	Y	.	.	1
	Corn	63	13	25	8
	Potato	Y	.	M	2
	Wheat	60	20	20	5
	Sugar beet	Y	.	.	3
	Oats	Y	.	.	1

*Y = reported benefit
**N = no reported benefit.
***M = mixed results.

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Table 9. Reported net returns from PA technology.

Technology	Crop, comments	Returns from Conventional Practice	VRT**	Reported* Net Return ($ $^{-1}$ acre)
VRT-NPK				
	Corn (See reference)	5.49	-1.15	-6.64
	Corn (See reference)	.	.	96.00-111.00
	Corn, 3 yrs., (See reference)	279.45	298.84	19.39
	Soybean-corn, 3 yrs., (See reference)	305.43	321.02	15.59
VRT-N				
	Beets, (See reference)	1025.00	1099.00	74.00 (gross) (48.25 net)
	Soybean-corn (Site 1) (See reference)	168.27	167.32	-0.95
	Soybean-corn (Site2) (See reference)	159.63	170.89	11.53
	Wheat (See reference)	68.53	76.18	7.65
	Wheat (See reference)	4.37	9.10	4.73
	Wheat, barley (See reference)	.	.	31.26
	Corn (See reference)	269.00	233.25	-35.75
	Corn (See reference)	197.00-315.00	204.00-326.00	7.00-11.00
	Corn (See reference) (application rate based on soil tests)	108.00	126.00	18.00
	Corn (See reference) (application rate based on yield map)	108.00	117.00	9.00
VRT-N,P				
	Wheat (See reference) (avg. yield goal used for fertilizer rec., 80 kg/ha)	131.94 107.45	106.57 108.44	-25.37 0.99
	Wheat (See reference) (Site-specific yield goal used for fertilizer rec.)	119.69	64.85	-54.84

*Note: values are the mean of lowest and highest results reported.
**Assume that VRT includes soil sampling costs (grid or otherwise), consulting fees, application costs, equipment purchase or rental costs, and any other additional costs (controller vs. manual applicators).

Table 9. Reported net returns from PA technology, continued.

Technology	Crop, comments, (Reference number)	Returns from Conventional Practice	VRT**	Reported* Net Return ($ $^{-1}$ acre)
VRT-P,K				
	Corn (See reference)	188.26	187.25	-1.01
	Corn, (See reference)	.	.	-2.41
	Corn, w/grid sampling (See reference)	.	.	9.14-40.89
	Wheat (See reference)	105.48	115.79	10.31
	Soybean, (See reference)	156.72	159.59	2.87
	Potato (See reference)	.	.	10-15
VRT-P				
	Corn (See reference)	139.63	142.86	3.23
VRT-pH (lime)				
	Corn (See reference) (Agro/Economic decisions combined)***	163.65	170.53	6.88
	Corn (See reference) (2.5-acre grid, Agro/Economic decisions combined)	154.74	159.01	4.26
	Corn (See reference) (1-acre grid, Agro/Economic decisions combined)	154.74	156.56	1.82
	Corn (See reference) (grid vs. conventional soil sampling compared)	39.04	36.14	2.90 (application costs, not net returns)
VRT-Seeding				
	Corn (See reference) (Agronomic Decision)			1.77
	Corn (See reference) (Economic Decision)			1.93
	Corn (See reference.) (using GIS and soil electrical conductivity)			1.00 (gross)

*Note: values are the mean of lowest and highest results reported.
**Assume that VRT includes soil sampling costs (grid or otherwise), consulting fees, application costs, equipment purchase or rental costs, and any other additional costs (controller vs. manual applicators).
***Agronomic decision: fertilizer recommendations are based on conventional rates usually found in extension publications. Economic decision: an increased fertilization rate applied to a specific area is justified where returns produced by an increase in crop yield equals (or is more than) the application costs of that additional amount applied.

Table 9. Reported net returns from PA technologies, continued.

Technology	Comments	Reported* Net Return ($ $^{-1}$ acre)
VRT		Net Return $^{-1}$ acre (Mean), (See reference)
Corn-P,K, grid soil tests		-$10.26
Corn-P,K, soil type		$0.77
Corn-Lime, grid soil test		$0.97
Corn-NPK and seeding		$14.15
		Net Return $^{-1}$ acre, (See reference)
Corn-VRT, soil testing (Simulation using actual production data.)	Information only, Uniform rate	$5.74
	Using VRT	$3.28
Corn-VRT-N (Based on Avg. Corn Price of $108/Mg, and two growing seasons.)	N Cost	Net Returns $^{-1}$ ha (N=12), (See reference)
	$0.55/lb	$32.49
	$0.64/lb	$36.40
	$0.73/lb	$38.49
Corn-VRT General (Simulation, Complete Partial Budget included)	Field Size/CV/Field Fertility	Net Return $^{-1}$ ha, (See reference)
	50-ha/25%/55 N kg/ha	-$108.05
	50-ha/25%/80 N kg/ha	-$107.52
	50-ha/50%/55 N kg/ha	-$105.53
	50-ha/50%/80 N kg/ha	-$72.92
	200-ha/25%/55 N kg/ha	-$18.23
	200-ha/25%/80 N kg/ha	-$17.61
	200-ha/50%/55 N kg/ha	-$15.71
	200-ha/50%/80 N kg/ha	$16.90
	500-ha/25%/55 N kg/ha	-$0.27
	500-ha/25%/80 N kg/ha	$0.35
	500-ha/50%/55 N kg/ha	$1.64
	500-ha/50%/80 N kg/ha	$80.00
GPS		
		Net Return $^{-1}$ ha, (See reference)
GPS (Corn, PA General) (Complete partial budget included)		$47.01
GPS (Benefits compared to foam marker systems)		Net Return $^{-1}$ acre, (See reference)
Producers owning equipment	GPS Guidance	-$0.29
	Lightbar only	$0.52
Custom applicators hired	GPS Guidance only	$0.30
	GPS Guidance	$0.10

Table 9. Reported net returns from PA technologies, continued.

Technology	Comments	Reported* Net Return ($ $^{-1}$ acre)
Grid Soil Sampling		
		Mean Net Return $^{-1}$ acre, (See reference)
Grid Soil Sampling (Base on VRT costs and returns. Fertilizer applied unknown.)	Grid point, 106-ft	-$0.40
	Grid point, 212-ft	-$0.25
	Grid point, 318-ft	$2.62
	Cell (area), 318-ft	-$6.79
		Mean Net Return $^{-1}$ acre, (See reference)
	Grid point, 100-ft	$2.44
	Grid point, 200-ft	$8.95
	Grid point, 300-ft	$10.16
Yield mapping†		
With VRT-P,K		Application costs reduced from $103.74 to $84.24 (low-yield land) and $96.24 (high-yield land, See reference)
VRT-pH, field drainage repairs		$713.21 (gross margin, See reference)
Weed Control		
		Net Return $^{-1}$ ha, (See reference)
Corn		$12.50
Corn (Simulation)	Weed pressure/patchiness	Net Return $^{-1}$ acre, (See reference)
	Low/Low	$0.01-7.64
Soybean (Simulation)	Weed pressure/patchiness	Net Return $^{-1}$ acre, (See reference)
	Low/Low	$1.94-11.64

†Includes combinations soil testing and various variable rate technologies.

(Return to Table Listing.)

CONCLUSIONS

This review the economic studies of precision agriculture indicates that about two thirds of all studies report benefits and another quarter report mix results. Consistent with previous reviews of the literature, high and consistent benefits are reported for site-specific N management in sugar beets. Modest positive returns are reported for variable rate lime, site-specific weed management, GPS guidance and variable rate plant populations when yield potentials vary widely in the field. Estimated profitability of VRT fertilizer ranges from substantial losses relative to whole field management, to substantial gains.

Profitability results do not appear to differ substantially by type of economic analysis, authorship of the report, or source of yield estimates. The percentage of studies using crop growth simulation or response functions which report positive benefits is about 10% higher than for studies using field trial data. Reported benefits from VRT are varied. Findings might be confused by crop type, application techniques, applied elements (N, P, and/or K), the quality of field reconnaissance maps and concomitant fertilizer recommendations, management strategies and field history, or uncontrollable variables such as weather or other climactic factors. Furthermore, unlike yield monitors, paybacks from variable rate systems are more of a function of time.

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Swinton, Scott, Stephen B. Harsh, and Mubrariq Ahmad. 1996. Whether and how to invest in site-specific crop management: results of focus group intreviews in Michigan, 1996. Staff paper 96-11, Department of Agricultural Economics, Michigan State University, East Lansing, MI., 1996. (http://agecon.lib.umn.edu/msu/sp97-37r.html.)

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Objective: To describe the current state of computer use in farm record keeping as applicable to VRT.

Methods: The author reviews pertinent literature regarding record keeping and database management of fertilizer and pesticide inputs.

Results/Conclusion: One of the authors' main concerns for VRT decision management and record keeping is the integration of laws requiring best management practices, development of reliable tracking systems, development of plant food applicators, database construction, decision aid software, and global agricultural information systems into a "paperless flow of data…" One goal would be to link these factors with mapping programs to better understand spatial relations characterizing individual fields. To achieve this goal, obstacles that need to be overcome by dealers and consultants include purchase of good software, learning how to use software by trial and error, and how to charge for services. The author provides hypothetical examples of his idealized system using plant food application and weed infestation remedies. The authors' conclusions were optimistic. He states: "[Though]…lag time for implementing VRT will continue…because our customers are still struggling with the technology…the long term savings in time, expenses, and input…that will come with VRT…will be worth the effort." A budget outlining at minimum the advantages of computerized record keeping as opposed to traditional "pen and paper" record keeping would be useful. Additionally, dealers and agricultural consultants seemed to be the focus of this report, not farmers. Dealerships and extension agents could promote projects or workshops designed to teach farmers how to use different record keeping software packages.

Crop: various
Technology: VRT, record keeping
Region: any

Ahmad, Saeed, Raymond J. Supalla, and William Miller. 1997. Precision farming for profits and environmental quality: problems and opportunities. Paper prepared for the Annual Meeting of Agricultural Economics Association, Toronto, Canada, July 27-30, 1997.

[1] Assembled by Dayton Lambert, Site-specific Management Center (SSMC), Purdue University, West Lafayette, IN.

Objective: To estimate the economic returns from variable rate application of N and water for corn, and to determine the effect of VRT-N and water management on nitrate leaching.

Methods: A field comprised of three soil types, each with different fertilizer demands, yield capacities, and nitrate leaching potential was hypothesized. Conventional and variable fertilizer and irrigation schedules were compared. Conventional N applications were assumed to be applied evenly over the entire field. Rates were based on soil tests extension recommendations that determined the optimal amount of N for expected yield. For VRT applications, N was assumed to be applied to specific grids of the field based on the soil requirements of a grid, and yield estimates based on the soil type. Economic benefits were defined as returns to land and management (net returns over variable costs). Fertilizer and water costs were considered the only costs that varied between management practices. EPIC was used to compare conventional and variable rate management strategies. A 15-year growing cycle was assumed.

Results/Conclusion: Corn yield decreased by 4.6%, but water use decreased 5.9%, and N applied decreased by 18.4% under the VRT management scenario. This translated into a $23.00 gain in returns per acre per year. In the simulation model, these returns offset the costs of VRT-N and water application. Results indicated that nitrate leaching below the root zone also decreased by 15.7%. The authors conclude that corn yield were higher under the VRT management system since N and water was applied at prescribed rates and in a more timely manner then the conventional management strategy, thus reducing plant stress. According to the authors, better timing of N application facilitates reduced N application to all soils. Precise irrigation schedules reduce leaching, also reducing the amount of N application. (Return to REFERENCES.)

Crop: corn
Technology: VRT-N, VRT-water
Region: Nebraska

Akridge, Jay, and Linda Whipker. 1998. Sharper look at the leading edge. Farm Chemicals, 161(6): 12-15. (Return to REFERENCES.)

Objective: Results of a survey conducted by the authors is reported. The objectives of the survey were to contribute insight to producers which directions precision agriculture dealers are headed as they modify precision agriculture technologies to fit their organizational structure and operations and needs as service providers.

Methods: A survey was sent to 1668 individuals associated with retail agronomy dealerships that provided precision technology equipment or services. The survey asked respondents about the services or technologies they provided, and the number of acres these services covered. Respondent's opinions about the future of these technologies and services were included in the survey as well.

Results/Conclusion: The Midwest represented 78% of 466 dealerships that responded to the survey. According to the authors, one of the first precision agriculture technologies adopted by producers are yield monitors. From this base, producers have an option to purchase yield maps, and data interpretation services. These could provide a foundation for grid based soil maps, then variable rate fertilizer recommendations followed by application. The survey results are presented below:

Table 10. Traditional agronomic services provided by respondents.

Traditional Agronomic Services Offered (N = 455)*	
Soil Sampling	97%
Custom fertilizer application	95%
Custom pesticide application	93%
Seed	92%
Consulting	89%
Field mapping	83%
Record keeping	62%
None of the above	<1%
Precision Agriculture Services Offered (N = 453)*	
Field mapping w/GIS	87%
Soil sampling w/GPS	82%
Yield monitor analysis	61%
Yield monitor sales/support	38%
Agronomic interpretation	77%

*1997 data

(Return to Table Listing.)

Table 11. Projected increases in demand for precision agriculture services by the year 2000.

Precision Agriculture Services Provided	Projected change in volume of services offered by 2000	Average Price Charged/acre (1997)	Average Price in other units
Field mapping	4% ↑ from 399	$1.77	$1-$75/map
Field mapping w/GPS	10% ↑ from 335	$3.27	$30-$50/hr
Soil sampling w/GPS	7% ↑ from 371	$6.11	$10-$30/sample/1-3 yrs.
Yield monitor analysis	13% ↑ from 276	$1.42	$30-$200/hr
Yield monitor support/sales	10% ↑ from 172	$2.02	$150-$1500/unit/yr $35-$75/hr
VRT - manual	8% ↑ from 190	$4.19	.
VRT - controller driven*	14% ↑ from 267	$5.22	$2-$3/acre, $1.5-$7.5/ton applied
VRT - controller driven**	15% ↑ from 140	$7.71	.
Data interpretation	9% ↑ from 349	$1.12	$30-$75/hr

*Single nutrient
**Multiple nutrient

(Return to Table Listing.)

Crop: na
Technology: precision agriculture/general
Region: Midwest

Akridge, Jay, and Linda Whipker. 1996. 1996 precision agricultural services dealership survey results. Staff paper 96-11, Center for Agricultural Business, Purdue University, West Lafayette, IN.

Akridge, Jay, and Linda Whipker. 1997. 1997 precision agricultural services dealership survey results. Staff paper 97-10, Center for Agricultural Business, Purdue University, West Lafayette, IN.

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Akridge, Jay, and Linda Whipker. 1999. 1999 precision agricultural services dealership survey results. Staff paper 99-6, Center for Agricultural Business, Purdue University, West Lafayette, IN.

Akridge, Jay, and Linda Whipker. 2000. 2000 precision agricultural services dealership survey results. Staff paper 00-04, Center for Agricultural Business, Purdue University, West Lafayette, IN.

Objective: To profile the dealership-field of precision agriculture in terms of services provided, types of dealerships, regional location, acres serviced, organizational structure, and future directions of precision agriculture as seen by firms.

Methods: An on-going study examines how dealerships are responding to demands for precision agriculture services. To date, 8,167 surveys have been mailed to dealerships specializing in retail sales of agricultural implements and consulting services across the United States. So far 1,629 (20%) storeowners, technical consultants, or managers have responded. Questions included which services dealerships provided, service fees, how they perceived clientele adoption of precision agriculture technologies, and what they saw as being the biggest development constraints in the precision agriculture business.

Results/Conclusion: Results from the 1998 survey appear higher than they do for other survey years since that dealerships known to specialize in precision agriculture were targeted. In 1999, the survey was randomized. Most respondents (67% ± 7) were from the Midwest region. The authors categorized dealerships as cooperatives, large independents (nation-wide service providers), and small independents (<25 outlets). The majority of Mid-western precision agriculture service providers were cooperative (45%) and small independent (44%) dealerships. Table 1 shows the percent of acreage managed under some form of precision agriculture technology between 1996 and 2000. Table 2 compares the percentage of the kinds of traditional agronomic services provided by dealerships. Table 3 presents the services in greatest demand by producers. A distinction is made between dealerships from the Midwest, and other dealerships.

Table 12. Total acreage (%) under some form of precision agriculture management, 1996-2000.

	Mid-Western States				Other Sates		
Acres serviced	1996	1997	1999	2000	1997	1999	2000
None	na	7.6	9.9	9.4	29.1	31.4	33.3
<10,000	21.0	7.1	5.3	6.9	18.8	17.9	17.5
10,000-25,000	22.0	26.5	20.1	20.7	18.2	21.4	23.8
25,001-50,000	30.0	29.8	35	29.3	21.2	16.4	11.1
50,000<	16.0	29	29.7	33.7	12.7	12.9	14.3
Base	566	238	283	276	165	140	126

(Return to Table Listing.)

Table 13. Traditional agronomic services (%) offered to producers by industry dealerships, 1996-2000.

	Mid-Western States				Other States			
Traditional Services	1996	1997	1999	2000	1996	1997	1999	2000
Soil sampling	93.0	91.1	89.4	91.3	81.0	74.6	71.2	71.0
Seed	85.3	83.5	94	92.3	75.0	74.0	79.9	77.1
Consulting	76.0	82.2	79.2	77.3	67.0	61.5	62.6	66.5
Record keeping	58.0	57.2	47.7	45.6	45.0	39.1	33.1	34.3
Field mapping/GIS	36.0	38.6	45.9	49.3	15.0	16.0	18.0	26.5
None of the above	Na	1.7	1.1	2.3	Na	9.5	6.5	6.2
Base	361	405*	283	279	204	405*	139	129

*Not differentiated in report.

(Return to Table Listing.)

Table 14. Breakdown (%) of precision agriculture services purchased by clientele from dealerships, 1996-2000.

Service	1996	1997	1999	2000
Soil sampling w/GPS	.	13.7	14.7	11.9
Field mapping	22.4	31.3	22.9	.
Field mapping w/GIS	18.8	7.9	11.4	9.9
Enhanced seed	18.8	26.7	39.0	.
VRT - seeding	.	1.8	.	.
VRT - seeding/GPS	.	0.7	.	.
VRT - Manual	.	15.3	11.1	13.4
VRT - controller/single	12.8	5.7	9.1	7.8
VRT - controller/multiple	.	5.3	5.2	4.7
Yield monitor - sales/support	18.5	14.3	11.7	15.4
Base	470	295	165	225

(Return to Table Listing.)

The most recent conclusion of this five-year study offered by the authors is though there is much interest in precision agriculture, and that this enthusiasm is likely to continue, dealerships do not foresee expanding their precision agriculture service base. Respondents anticipate that the demand for precision agriculture services will grow within the next three years. The authors' suggest that the precision agriculture technology composite is better suited to the Midwest than other regions of the United States because of the kinds of cropping programs and farm sizes in the region. They also estimate that adoption rates will be highest amongst cooperatives and larger, national dealership chains.

Anonymous. 1996. Grids' value for beets. The Sugar beet Grower. February, 1996, p. 14-15. (Return to REFERENCES.)

Objective: The report summarizes grid soil testing/variable rate fertilizer application research results from a university. The objective of the study was to: (1) to determine the nitrate-nitrogen soil profile of a sugar beet field to a maximum depth of four feet; (2) to compare economic returns of grid-based variable rate fertilizer application with conventional fertilizer application methods; and (3) to continue this study over a period of years to explain nitrate-nitrogen changes in the field over time.

Results/Conclusion: Grid soil sampling results ranged from 45 to 144 lbs of nitrate-nitrogen per acre. Conventional soil testing techniques where probes are assigned randomly to points in a field resulted in a field-wide average of 117 lbs of nitrate-nitrogen per acre. Grid sampling-variable rate fertilization generated a net return of $48 more per acre than the conventional fertility management strategy. Grid sampling and soil test costs were $12.73/acre compared to the $0.68/acre cost of the conventional soil sampling method. Variable rate fertilizer application was priced at $9.00/acre, whereas the conventional fertilizer application method was $3.50/acre. Grid-based soil test results called for an additional application of 41-lbs of nitrogen, adding $8.20. The total cost for the grid sampling/variable rate application method was $25.75/acre. The gross income per acre under the VRT-N strategy was $74/acre, with a net return of $48.25. The author concludes that returns will vary depending on the spatial variability of nitrogen throughout the field. (RETURN TO INTRODUCTION.)

Crop: sugar beets
Technology: grid sampling/VRT
Region: Minnesota

Atherton, B.C., M.T. Morgan, S.A. Shearer, T.S. Stombaugh, and A.D. Ward. 1999. Site-specific farming: a perspective on information needs, benefits and limitations. Journal of Water and Soil Conservation, 2nd Quarter, 1999. (Return to REFERENCES.)

Objective: To identify the kinds of information needed to practice site-specific farming. Traditional and new data collection techniques are discussed in terms of future needs that will arise as precision agriculture develops.

Methods: The authors use personal experience and additional reports to describe the components of site-specific management, especially in terms of data collection and information management.

Results/Conclusion: The authors list the main factors influencing yield variability. Soil factors include moisture content, nutrient load, pH, topsoil depth, cation exchange capacity, texture and mineral composition, bacteria and other organisms, and air. Management decisions affect the health of soil, hence plant growth. Knowing the extent to these factors spatially vary across a field provides producers with an interrelated series of information upon which informed fertilizer management recommendations can be made. Topography such as relative elevation, slope, and landscape position influences the physical properties of soil. Less organic matter and thin topsoil depths are correlated with slope. Low-lying areas drain poorly and often have higher levels of organic matter. Yield is affected by the topographical spatial variability. Elevation and slope have accounted for 49-84% of within field yield variability in wheat. Climatological factors influence the kinds of crops that can be grown in a region, along with plant disease pathogenesis and irrigation and drainage needs, and accounts for much of the seasonal variation in yields. Climates directly affects soil moisture content, hence yield. Plant stress caused by excess water explained 69% of yield variability in an Iowa field.

Climatological effects are best understood by compiling season-by-season data. Pests, including insects, plant pathogens, and weeds are responsible for approximately 37% of pre-harvest crop losses. An Iowa study documented returns of 458% when herbicides and pesticides were used with corn. However, pests can display spatial variability across a field. Managing pests at threshold levels in specific areas are an alternative to whole-field application of herbicides or pesticides. Integrated pest management is another form of VRT in that pesticides are employed when the benefits of spraying are greater than application costs. Cultural practices include plant population density, planting dates, row orientation, and dates of plant maturity. Yield maps provide a tool for tracking plant population growth cycles, and can link yield variability and specific growth stages to field variables. Data can be collected manually or automatically. Manual collection, such as soil sampling and scouting, can be time consuming and labor intensive. On-the-go data collection techniques employ GPS and yield monitors, and can be adapted to other farm management operations such as soil sampling and elevation mapping. Remote sensing has much potential, yet little information exists about its economic feasibility. Remote sensing can provide whole-field information. When used with GIS, wider, off-farm contexts affecting yield variability can be discerned, providing the producer a composite of information from which site-specific as well as whole farm management decisions can be made. Obstacles impeding adoption of remote sensing include specialized instrument calibration, the indirect, subjective nature of the data generated, limited end-user control, and the image acquisition time lag. The authors conclude that there is currently no global, unified set of information characteristic of site-specific management. Information selection will be based on collection costs, the timeframe the information is valid, the utility of the data in estimating yield, and its ability to reduce environmental risk.

Crop: any, general
Technology: VRT, general description
Region: United States

Audsley, E. 1993. Operational research analysis of patch spraying. Crop Protection, 12: 111-119. (Return to REFERENCES.)

Objective: To simulate the economic returns generated by controlling weeds using variable, herbicide patch spraying. Questions asked include at what weed population density economically warrants herbicide application? And, is it more profitable to spray an entire field at one, scheduled time, or spray weed-infested sections as needed.

Methods: The model assumes that although weed patchiness can be caused by a number of factors (mainly anthropogenic), weed seedbank density in one patch is independent of weed populations in other patches. Weed biological characteristics used in the model include the number of weeds that successfully reproduce, seed viability and longevity, plant fecundity, and germination time and rate. Other model parameters include herbicide cost, herbicide kill rate, patch size, and crop-weed competition for space. A time period of ten years was simulated. Spray strategies compared were patch spraying and whole field spraying.

Results/Conclusion: The most obvious advantage of patch spraying is that herbicide is not wasted on weedless portions of the field. Weed competition had little effect on the feasibility of patch spraying. Overall costs of the two methods were not sensitive to a plant density threshold per m^2. However, patch spraying is not profitable at extremely high weed seed densities or where there are large, weedy patches. Herbicide efficiency also determined whether patch spraying was economically efficient. Patch spraying is more profitable with more effective herbicides.

Crop: na (simulation)
Technology: VRT-weeds
Region: U.K.

Babcock, Bruce A., and Gregory R. Paustch. 1998. Moving from uniform to variable fertilizer rates on Iowa corn: effects on rates and returns. Journal of Agricultural and Resource Economics 23(2): 385-400. (Return to REFERENCES.)

Objective: To determine the value of variable rate technology compared to conventional, single-rate N applications in economic and environmental terms. Differences in yield, profits, and N use are projected for individual fields and extrapolated to include counties as producers switch from single-rate N application to VRTN. The authors used data from previous studies to determine model parameters.

Methods: The authors randomly select 240 sites from 20 locations representing 12 counties. Management histories of each site, along with yield potentials were used as guides to fertilizer application rates in the model. Yield potential was correlated with soil maps. Using this information, a model was designed to analyze the environmental and economic costs and benefits absorbed by producers if they switched from single-rate N application to VRTN.

Results/Conclusion: The value of VRT is not viewed in terms of yield increases and input savings. Rather, VRT is a method to avoid N misapplication over an entire field. This distinction provides both production and environmental benefits by correcting N soil overloading and waste. As the price of N fertilizer increases, so does the value of VRTN. The converse is equally true. Simulated results were generated after filtering data from 20 randomly selected sites representing 12 counties through the model. Findings suggest that 66% of the acreage farmed using single-rate N application would be oversupplied with nitrogen, 4% would be undersupplied, while 30% would receive optimal amounts. If farmers were to switch from single-rate technology to VRT, gross returns would increase $4.03 (range). When all counties were combined, returns over fertilizer cost were $4.44/acre. Increases in returns were mainly due to decreases in N application. When producers are unable to vary fertilizer rates, or they lack information where the best-yielding soils are located in a field, then they have reason to fertilize the highest-yielding soils even if it is not necessary. In contrast, producers using VRT reduce production costs by decreasing amounts of fertilizer applied. The $4.44/acre increase in returns using VRT instead of a single rate application may be overestimated. The values presented by the authors do not include the costs of switching over to VRT. The authors estimate the cost/acre of VRT to be $1.50. According to their figures, subtracting this value from the gross returns, the minimum and maximum returns are $0.02 and $1.82, respectively, with a range of $1.80. Still, according to their model, VRT is cost effective. Whether or not these benefits can be realized remains to be determined from field trails and further analysis.

Crop: corn
Technology: VRTN, modeling
Region: Iowa, any

Barnhisel, R.I., M.J. Bitzer, J.H. Grove, and S.A. Shearer. 1995. Agronomic benefits of varying corn seed populations: a central Kentucky Study. Precision agriculture: proceedings of the 3rd international conference, June 23-26, Minneapolis, MN, p.957-966, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To investigate the economic feasibility of varying seeding rates according to soil depth, and to compare yields when planting density is varied according to soil type to conventional seeding strategies where seed is planted based on plant population density.

Methods: Three seeding rates were evaluated: 45, 75, and 70 K/ha. Two constant seeding rates were checks: 49 and 64 K/ha. Soil tests were used to determine soil fertility and topsoil depth. Samples were taken at three different depths from 0 to 20-cm below the surface. For each treatment, seeds at rates prescribed based on topsoil depths (<15, 15-20, 20< cm) were planted in 3-m wide strips. Economic results were based on $1/1000 seeds and $3.00/bu corn.

Results/Conclusion: Corn yield on topsoil less than 15-cm deep was greater for low planting density treatment than they were for the seeding rates. The converse was true for deep (20< cm) topsoil profiles where higher seeding rates generated higher yields. Varying seeding rates according to topsoil depth produced more corn than constant seeding rates. Net returns for variable seeding were higher ($771.60/ha) than they were for conventional, constant seeding rates of 49 and 64 K/ha ($720.00 and $691.00, respectively). The authors caution that their results may be only applicable to Kentucky corn farming, as the topography lends itself to rolling hills were farms are usually located on upland sites and highly variable soil depths.

Crop: corn
Technology: VRT-seeding
Region: Kentucky

Bauer, Troy A., and David A. Mortensen. 1992. A comparison of economic and economic optimum thresholds for two annual weeds in soybeans. Weed Technology, 6(1): 228-235. (Return to REFERENCES.)

Objective: To produce a model that estimates the economic optimum threshold for controlling nuisance velvetleaf and sunflower populations in soybean crops.

Methods: A simulation model iterated for 15-yrs was developed to determine the economic differences between continuous and variable spray management strategies for controlling weed populations in soybean production fields. The model was based on the biology of velvetleaf: seed age-class and longevity, germination rates, fecundity, growth rate, the number of seedling surviving to reproduction, and seedbank survival following tillage or other mechanical or chemical field manipulations. The economic model assumed a linear decline in soybean production with increasing velvetleaf population densities. A soybean yield function with and without weeds was derived. Economic returns were a function of the crop yield function, crop price, variable (purchased materials, fuel, repairs and maintenance, rent, and operating expense interest) and fixed (machinery purchases, real estate taxes, interest on land) costs, overhead and management, labor costs, and herbicide cost. The simulation compared an annual, continuous spray management strategy to an economically optimal threshold spraying strategy. The latter approach recognized year-to-year variability in weed populations. With this expectation, more or less herbicide can be applied depending on estimated weed densities for a given year.

Results/Conclusion: The economically optimum threshold (EOT) weed management approach was superior to the continuous spray management approach. Over a 15-yr period, returns per hectare per year for the EOT strategy were $119.45, whereas returns for the continuous spray strategy was only $2.51.

Crop: soybean
Technology: VRT-weeds
Region: Nebraska

Beuerlein, Jim, and Walter Schmidt. 1993. Grid soil sampling and fertilization. Agronomy and Technical Report 9302, Ohio State University. (Return to REFERENCES.)

Objective: In this extension publication, the authors outline the benefits of grid soil sampling, and describe in detail field trail results using different grid sampling techniques and grid sizes. A partial budget is used to determine the profitability of grid soil sampling compared conventional soil sampling methods.

Methods: In this extension publication, the authors compare different grid soil sampling strategies to determine element NPK values in a 144-acre field. Soil samples were taken at 60, 120, 180, and 200-foot intervals in 540-ft straight lines. The costs for each strategy were determined. Tests determined what appropriate grid sizes should be. Once grids sizes were determined, three dimensional fertility zone maps were constructed. Maps indicated the spatial variation of P and K values. A partial budget details fertilizer cost differences between conventional and grid soil sampling practices, and net returns after prescribed fertilizer rates based on grid soil sampling were applied to crops.

Results/Conclusion: Depending on the sampling distance and the number of samples, P concentrations varied 23 to 33-lbs of P per acre. The authors' pint out that if only one soil sample had been taken, the test values would range would be 10 to 63-lbs per acre. The authors conclude that fertilization programs based on grid sampling might be less profitable for fields where low soil fertility values are widespread. Conversely, in fields where soil fertility is highly variable, returns from grid soil sampling are realizable. Preliminary sampling should be conducted to determine appropriate grid sizes. Grid size and spacing should be optimal in the sense that they capture the spatial variability of micronutrients; testing costs will soar with too many samples, but larger grid sizes might mute local areas where nutrient loads are highly variable. The authors suggest that grid sampling and prescriptive measures taken can correct a field over time such that it can be managed using conventional practices, or uniform application rates.

Table 15.. The effect of soil sampling grid size on the number of samples per 10-acre unit and cost of soil analysis.

Grid Spacing (ft)	Samples/10-acres	Analysis Cost/10-acres*
60	120	600
120	24	120
180	13	65
240	8	40
300	5	25
360	3	15
420	3	13
480	2	10
Rectangular		
60 x 120	60	300
60 x 180	40	200
60 x 240	30	150
60 x 300	24	120
60 x 360	20	100
60 x 420	17	85
60 x 480	15	75

(Return to Table Listing.)

Table 16. Fertilization cost comparisons of grid and conventional methods of soil sampling.

	Cost/acre	Annual cost for 8 years
Grid method		
Soil sampling and testing (100' x 100' grid)		$3.26
Corrective fertilizer		21.50
Initial precision spreading		$1.56
Annual crop removal fertilizer		$16.50
Annual fertilizer application		$2.50
	Total	$45.32
Conventional method		
Annual plus Buildup P and K		$38.50
Annual fertilizer application		$2.50
	Total	$41.00

(Return to Table Listing.)

Table 17. Returns to grid soil sampling after correcting for P levels.

Sample*	Original Yield		Post-correction Yield		Income difference**		
	Soybean	Corn	Soybean	Corn	Soybean	Corn	Avg.
	(Bu/acre)		(Bu/acre)		($/acre)		
A	21	82	47	106	156	60	108
B	47	159	58	179	64	50	58
C	34	122	54	152	119	75	97

*A, B, and C represent 12-acres areas of lowest and highest, and the average of 144 acres, respectively.
**Soybeans=$6/bu, Corn=$2.50/bu (Return to Table Listing.)

Crop: corn, soybean
Technology: VRT, grid soil sampling
Region: Ohio

Bongiovanni, Rodolfo, and James Lowenberg-DeBoer. 1998. Economics of variable rate lime in Indiana. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1653-1665, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: Using a spreadsheet model, the authors determine optimum lime rates for specific locations in a field. This study fits yield responses to field data from controlled experiments investigating liming rates. The authors ask whether site-specific pH prescriptions are profitable over a 4-year cycle of soil sampling, and if 2.5-acre grids provide sufficient information to achieve this. The decision whether or not one should adopt variable rate liming strategies is addressed based on the findings.

Methods: Three liming strategies are compared. The first is a site-specific management strategy (SSM) using agronomic recommendations. The second is SSM using economic rules, specifically, that marginal value product must equal marginal factor costs: the additional value gained from applying an extra unit of fertilizer must at least equal the application cost of the material added. The third analyzed is information strategy. This strategy assumed the producer uses agronomic recommendations from university or custom extension services, that s/he has access to grid-based soil test information, but does not have the machinery (variable rate equipment) to mobilize the information. Here, a uniform rate is applied over the entire field at a rate that will bring an area of the field with the lowest pH up to the desired or recommended level. These strategies are compared to whole field management strategies where uniform lime application rates are used over the entire field based on conventional recommendations. Doing nothing is used as a control case. Additionally, a sensitivity analysis examining whether 1.0-acre grids are more effective than 2.5-acre grids when testing soil is conducted.

Results/Conclusion: The results indicate that variable rate application of lime is profitable as a stand-alone activity. The SSM-Economic strategy was the most profitable management option. The next most profitable strategy was the SSM-Agronomic, followed by whole field management, then doing nothing. Information strategy was less profitable than whole field management because of the large amounts of lime needed to bring the lowest portions of the field up to acceptable rates. In the sensitivity analysis, returns from 1.0-acre grid were less than 2.5-acre grids because of the extra amount of sampling needed to cover the field. However, SSM with lime using a 2.5-acre grid is more profitable than whole field management using grids of equal size. The data are from mixed sources (18 different states), possibly confounding the results by regional effects. The study combined regional averages ignoring the possibility that the data set may have been skewed. (Return to Table 9.)

Crop: corn, soybean
Technology: VRT
Region: Indiana

Bongiovanni, Rodolfo, and James Lowenberg-DeBoer. 2000. Nitrogen management in corn using site-specific crop response estimates from a spatial regression model. Paper presented at the 5th International Precision Agriculture conference, Minneapolis, MN, July 2000. (Return to REFERENCES.)

Objective: To determine whether yield monitor data is useful for estimating site-specific crop N response, and to compare to techniques for determining corn yield response functions: ordinary least squares (OLS) and spatial autocorrelation regression (SAR). Yield monitor data was analyzed using spatial regression. Following spatial regression analysis of yield monitor data, the profitability of site-specific N management (VRT) using the above diagnostic methods was determined using a partial budget analysis.

Profitability analysis compared returns from variable rate N management to a uniform rate N management strategy. The results presented are the first in a series of studies to be conducted over four growing seasons.

Methods: Data from four farms was collected to estimate N response. Variable rate nitrogen treatments were 29, 53, 66, 106, and 131.5-kg/ha. Three soil types were identified based on topography (hill, slope, and low). Control strips received no nitrogen treatment. A randomized complete block design was used during the trials. Within each block treatments were randomized. Nitrogen rates were consistent for an entire strip, and the highest N rate for each site was higher than the estimated maximum yield level. A yield monitor was used during harvest. Corn response to N functions was estimated using spatial econometric techniques. Briefly, this diagnostic technique determines the extent and strength to which different fertility zones are related. For example, the N-value of a fertility zone situated in a low-lying area may be strongly correlated with the N-values of a contiguous zone with a slope or higher elevation. Additional variables such as rainfall or hydrology will affect the N-values of the lower zone because of its location relative to the higher zone. Spatial econometrics aims to parse these relations and determine the strength of dependencies between multiple variables. Results from this test yields response function coefficients specific to a landscape management zone. The foundations of these response functions are the strength of the relation between the variables defining that zone (slope, N-values, pH, water holding capacity). Software packages capable of handling such multivariate analyses are currently ArcView and SpaceStat. The accuracy of ordinary least squares and spatial autocorrelated regression methods for determining the economic returns from individual production zones were compared, especially in terms of the economic feasibility of VRT-N.

Results/Conclusion: Preliminary results of the study indicate that the SAR method was more accurate than OLS when determining corn yield response functions. Marginal analysis determined economic feasibility of uniform versus variable rate N treatments. It is assumed that the added value of the crop gained by adding additional N is equivalent to the application costs of this additional unit. Profits are maximized when the marginal value product equals the marginal factor cost. Returns varied across soil types (based on topography zones), and according to the regression model used. Variable rate nitrogen application was more profitable then uniform rate treatments in all but 5 treatments (combining OLS/SAR comparisons, 95%). (Return to Table 9.)

Crop: corn
Technology: VRTN
Region: Argentina

Braga, R.P., J.W. Jones, and B. Basso. 1999. Weather induced variability in site-specific management profitability: a case study. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1853-1863, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The authors ask the following questions: what are the benefits of precision agriculture, how much precision is needed to realize benefits, and what risks are associated with weather variability? Based on the last question, the authors ask if precision agriculture is only beneficial during good years rather then bad.

Methods: The study site was a hypothetical 60-ha field represented by four soil types. Variable rate sprayers were available, and cost \$9.00 ha $^{-1}$. The conventional application rate for the farmer was 180 kg N ha $^{-1}$ split in two applications. A yield function incorporating these parameters was derived. The model simulated 35 years of crop production.

Results/Conclusion: Higher grain yields were achieved during better weather years for similar N application rates. However, combining soil types and weather years did not increase the accuracy of the scenarios studied. During the simulation, price per unit N was higher for variably applied N, which reduced the N recommendation rates resulting in lower crop yields. The authors assumed that price drops in N fertilizer would influence this result. Site-specific management did not reduce risks associated with weather patterns. The time sequence used in the model was not autocorrelated. That is, the authors assume that N carry-over effects could be accounted for if time sequences overlapped with one another, instead of being independently distributed. Gains (net return) varied according to soil type. An enterprise budget was not included in the analysis, perhaps for the simplicity's sake. However, the authors mention that in order to obtain realistic figures describing the economic feasibility of site-specific management, an analysis must include detailed breakdowns of farm inputs and outputs, along with off-farm variables that influence production.

Crop: corn
Technology: VRTN, modeling
Region: Michigan

Bruulsema, T.W., G.L. Malzer, P.C. Davis, and P.J. Copeland. 1996. Spatial relationships of soil nitrogen with corn yield response to applied nitrogen. Precision agriculture: proceedings of the 3rd international conference, June 23-26, Minneapolis, MN, p.505-512, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The utility of landscape characteristics and soil attributes as estimators of crop response to nitrogen was examined. Corn yields were interpolated to points where soil nitrogen indices had been measured to predict nitrogen response curves. No economic analysis was provided.

Methods: Three corn production fields of 5 of 6-acres were divided into 5m strips. Four to six strips were used as replicates for each of six N-application treatments. A radar controlled variable-rate applicator was used to apply nitrogen to each strip. Differences in field elevation were determined at each site. At each soil sample spot within sites, corn yield corresponding to each treatment was extrapolated by estimating corn yields measured in each segment. Profitability was evaluated subtracting yield returns from implementation costs. No detailed budget was provided.

Results/Conclusions: Relationships between soil N indices, landscape characteristics, and yield responses was weaker than expected. There were no differences detected between soil nitrogen indices collected in the spring, or those that were collected in the fall. The soil test with the highest coefficient of correlation was total N. A positive correlation was found between elevation (higher ground), soil photone (lighter color), and change in crop yield at one of the sites. However, when nitrogen was considered, a general trend was found where production response to nitrogen correlated with low-lying areas of fields. The authors attributed stronger yield responses to nitrogen in low-lying areas to field saturation. The correlation was stronger between nitrogen and crop yield to soil N indices than to economically optimal nitrogen rates (EONR). The authors conclude that VRTN profitability will be maximized when yield changes are the primary focus, not EONR.

Crop: corn
Technology: VRTN
Region: Minnesota

Buchholz, Daryl D. Unknown date. Missouri grid sampling project. Unpublished document. University of Missouri Soil Fertility, Agronomy Extension, 214 Waters Hall, Columbia, MO 65211. (Return to REFERENCES or Table 9.)

Objective: To outline what procedures used to produce field maps, determine field fertility variability, worked best during a 3-year study examining the efficacy and economic feasibility of variable rate application technology in Missouri. Net return to VRT-P, K is presented in rudimentary partial budget form.

Methods: Soil quality was determined by grid sampling at three sites. Grid samples were taken in 330-ft intervals (2.5-acres). Twelve soil sub-samples were taken in a 10-ft radius at grid points. Results were interpreted as a contour map. Yield responses combined with soil test information determined VRT-P, K application rates.

Results/Conclusions: Compared to conventional, uniform P and K treatments, VRT-P, K yielded positive returns at each site. At site 1 (80-acres), net returns were $40.89/acre. At this site, phosphate was the only element varied. Returns to VRT for variable P and K applications averaged $16.38 at site 2 (82-acres). At site 3 total gains to varied P and K was and $9.14.

Crop: corn
Technology: VRT-P,K
Region: Missouri

Bullock, Donald G., David S. Bullock, Emerson D. Nafziger, Thomas A. Doerge, Steven R. Paszkiewicz, Paul R. Carter, and Todd A. Peterson. 1998. Does variable rate seeding of corn pay? Agronomy Journal 90:830-836. (Return to REFERENCES.)

Objective: To estimate the economic value of variable seeding of corn. Field quality and economically optimal plant density were correlated to determine the distribution of field fertility zones.

Methods: The authors define the economic theory of precision agriculture. First, a field is sub-divided into management units. Each unit is subject to three factors. The first vector included edaphic, hydrological, and topographical characteristics of the parcel. The second vector set includes inputs controlled by the producer, such as seeding density or fertilizer rate and application timing. The third vector set includes stochastic factors, such as weather or market forces. Yield responses are determined by a function defined by these variables. The authors evaluate the utility of basing fertilization management decisions on the first set of characteristics. A data set provided by an agronomic company was used in the model.

Results/Conclusion: Site-specific economically optimal plant densities ranged from 44,000 to 104,000 plants/ha, with a mean planting rate of 67,900 plants/ha. A linear correlation between optimal plant densities and site qualities revealed that site quality was not a good estimator of plant density ($r = 0.27$). However, the findings indicate that where site quality is relatively modest, considerably higher plant densities are required to achieve optimality. This suggests that not having adequate seed in field sections of modest quality is a downside risk. To determine the economic advantages of variable rate seeding, the authors tested four scenarios. Each scenario was compared to a uniform seeding strategy. In the first scenario, the farmer is assumed to know the yield response of a given location in the field and can apply the recommended seed rate to that area. In the second scenario, the farmer does not have the ability to vary seed application, yet knows that yield responses vary throughout the field. The farmer has the ability to vary seeding, yet does not know the fertility variability of the field in the third scenario. In the fourth scenario, the farmer does not know the yield responses across the field, nor does he have the capacity to vary seeding. These scenarios were tested under four different field qualities (in terms expected yield, Mg ha^{-1}). When scenarios 1 and 2 were compared, VRS was profitable for the farmer capable of varying seed application (range $9.83 to $12.83). When scenarios 3 and 4 were compared, returns from VRS were slightly greater than those from uniform seeding (range $0.15 to $1.49). Returns from the value of knowing yield responses under a uniform seeding application protocol ranged from $0.01 to $0.06. The authors conclude that, at its current stage of development, VRS is of little economic benefit to producers. VRS would only be profitable to farmers who knew a great deal about the correlation between yield and plant density for each section of a field. Generation of this knowledge entails many years of production data to generate yield response function coefficients specific to a field. The authors raise some valid points about the costs associated with information gathering, and whether those costs will pay for themselves within a given time frame. As a stand-alone practice, VRS may not presently be economically feasible.

Crop: corn
Technology: VRTN
Region: Mid-West

Bullock, David S. and Donald G. Bullock. 1999. From agronomic research to farm management guidelines: a primer on the economics of information and precision technology. Forthcoming, *Precision Agriculture*. (Return to REFERENCES.)

Objective: The authors attempt to demonstrate the complementarity between quality information and precision agriculture using a dynamic optimization model with stochastic components.

Methods: As the model is built, stochastic components (non-manageable factors such as rainfall) are included step by step to demonstrate the increasing complexity of the economics of decision making underlying precision agriculture. As each component is included in the model, the value of information about that variable is revealed. For purposes of simplicity, the authors posit a hypothetical field with two known soil depths. Uniform or variable fertilizer application rates are programmed into the model generating a composite of management options from which farmers representing different risk profiles might choose.

Results/Conclusions: From their model the authors conclude that precision agriculture will not be worthwhile to a decision maker who does not have adequate information. The authors define "adequate information" as perfect information, including knowledge of probability distributions for weather patterns, external markets, or reasonable estimates for expected crops yields. It is no surprise to the authors that farmers possess incomplete knowledge about their fields since the main technologies of precision agriculture (PA) are not readily available to the public, economically or otherwise. The authors suggest that PA will not take of in the public domain until the conditions that render it economically optimal are determined. For now, PA will remain in the domain of research and development. That farmers do not have access to the tools supporting PA does not necessarily mean that farmers "possess relatively little information about their fields." Having tools that can fine-tune the soil profile and chemical composition of a field down to the square foot may generate information useful for answering some questions. However, whether or not this information has any production value remains in question. What needs to be determined is which tools will aid a farmer in the decision making process, and in what combinations. The combination of technologies will of course be dependent upon socio-economic and ecological factors, such as the risk profile of the individual, the history of the farm, the region where the farm is located, and which crops are grown, and when.

Crop: Simulation
Technology: Simulation/dynamic optimization
Region: NA

Carr, P.M., G.R. Carlson, J.S. Jacobson, G.A. Nielsen, and E.O. Skogley. 1991. Farming soils, not fields: a strategy for increasing fertilizer profitability. Journal of Production Agriculture, 4(1): 57-67. (Return to REFERENCES.)

Objective: To compare crop yields between different soil types within fields, and the economic feasibility practicing site-specific fertility management.

Methods: Fertility zones of four fields having between two and ten soil types were mapped using aerial photography and satellite imagery, soil survey reports, and producer knowledge of the field. Soil tests results for N, P, and K were based on the average of four core samples taken from 0 to 48-in below the surface. Recommended fertilizer rates were based on yield goals, soil test results from management units (as defined by soil test results), and university extension guidelines. Uniform whole field, optimal, and site-specific treatments were compared with a check treatment (no fertilizer). Fertilizer rate recommendations for the optimum treatments were based on the information collected site-specific information, averaged, and applied as a whole field application. Fertilizer was applied in strips using a randomized block design. Twenty yield samples were taken from each management zone at harvest.

Results/Conclusion: High-yielding soil types produced two times as much grain than low-yielding soils. There were no statistical differences in returns between uniform, optimal, and site-specific managed units. However, the optimal fertilizer management strategy generated $20/ha more returns than the site-specific management treatments. (Return to Table 9.)

Crop: wheat
Technology: VRT
Region: Montana

Casaday, William W., and Raymond E. Massey. 1999. The growth and development of precision agriculture service providers. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1757-1765, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To provide a summary of the precision-agriculture related services, and their current prices.

Methods: A survey was to twenty-seven agricultural dealerships that offered precision agriculture related services.

Results/Conclusion: The authors conclude that precision farming had evolved as a series of clusters in different areas of the United States. Agriculture dealerships serve as hubs providing specialized precision agriculture services. Service providers expect that the demand for precision agriculture related technologies would continue to grow, especially in the domain of variable rate application technologies. Other costs not included in this analysis were lag-time associated with training and learning, human capital costs, and additional peripheral costs such as computer hardware and software. It was also assumed that individuals would hire a consultant to carry out precision agriculture related activities instead of implementing the tasks themselves.

Table 18. Costs per acre for various PA technologies.

Technology	Cost (acre $^{-1}$)*
Soil Testing and maps	$3.75 - $11.00
Variable Rate Applicator (Including Truck)	$300,000
Variable Rate Applicator	$15,000 - $20,000
Variable Rate Application	$1.00 - $5.00
Variable Rate Application (<3 products)	$1.00 - $25.0
Yield Monitoring - Equipment Cost	$7,000 - $10,000
Yield Maps	$0.25 - $1.00
Service Charge	$2.63 - $4.07

*Missouri, 1998 (Return to Table Listing.)

Crop: na
Technology: precision agriculture, general
Region: Missouri

Cattanach, A., D. Franzen, and L. Smith. 1996. Grid soil testing and variable rate fertilizer application effects on sugar beet yield and quality. Precision agriculture: proceedings of the 3rd international conference, June 23-26, Minneapolis, MN, p.1033-1038. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: Three trials conducted over two years investigated field spatial variability of N, P, and K. Variable rate N application (VRTN) based on soil information collected using grid sampling was compared to uniform N application methods based on whole field soil testing.

Methods: The study sites were three fields ranging from 67 to 90-ha. Sugar beets were the primary crops in rotation with grains. Three depths were tested for nitrate-N: 0-15, 16-60, and 61-105-cm. Grid sizes ranged from 1.25 to 1.60-ha. Six to eight soil core samples were taken in each grid for VRTN recommendations. Recommendations for uniform application rates were based on 30 to 40 core samples taken randomly over across the field. Each field was divided into strips. Each strip received either a uniform N application, or a VRTN application. A crude partial budget evaluated the profitability of technology employed.

Results/Conclusions: Not surprisingly, grid coil sample results were more accurate than conventional soil testing results. Conventional soil testing procedures resulted in 50 to

76% of the field being underfertilized. At all sites, yield response and sucrose content from VRTN and grid sampling techniques were greater than whole field soil analysis and uniform N application. Subtracting the additional costs of grid sampling and VRTN from the yield, a net return of $143.00/ha was achieved. Instead of lumping costs of VRTN and grid sample together, it might be useful to present the costs as a line item budget. How useful would a "microanalysis" be when looking at the unsubstantiated reportss of these technologies? Furthermore, an itemized budget might uncover some costs not foreseen or included in the analysis as presented. Some costs not directly associated with VRTN/grid sampling might influence the outcome of the analysis.

Crop: sugar beet
Technology: VRTN, grid soil sampling
Region: Minnesota, North Dakota

Clay, S.A., G.J. Lems, D.E. Clay, M.M. Ellsbury, and F. Forcella. 1999. Targeting precision agrichemical applications to increase productivity. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1699-1707, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To compare pre- and post-emergence herbicide recommendations based on models simulating resources available to producers, historical information about previous treatment protocol, and other decision based on price, rebates, and other factors.

Methods: Three trials were conducted on a field under a soybean-corn rotation. Five treatments were replicated four times using a randomized complete block design. Three recommendations generated using a bio-economic model were compared to a producer's routine herbicide application rate, and a rate recommended by the local extension facility.

Results/Conclusion: The herbicide recommendations generated by the model had equal or higher net returns than the conventional treatment of the producer. In all cases, the strategies proposed by the models were less expensive than the treatment of the producer. The results suggest that recommendations based site-specific information generated by the models when actual field data is used can improve profitability.

Crop: soybean
Technology: VRT
Region: Minnesota

Colburn, J.W. 1999. Soil doctor multi-parameter, real-time soil sensor and concurrent input control system. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1693, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To evaluate the effectiveness of the *Soil Doctor* variable application system, while providing the theoretical background behind its operation and application. An economic analysis is provided.

Methods: A series of yield functions are presented in lieu of soil quality parameters N, P, and K. Nitrogen is used throughout the report as an example.

Results/Conclusion: Field variability, yield response curves, and average soil nitrogen-nitrate levels determine the potential amount of N savings and possible yield increase. The authors conclude that the success of any new technology introduced into the agricultural arena depends upon the returns on investment it generates. The authors suggest that the success of the *Soil Doctor* system may in part be due to the high calibration levels recommended to tolerable nitrogen-nitrate levels by the manufacturers. The higher calibration levels mean more N will be applied over a certain area that is detected as being N-deficient. Nonetheless, as a variable rate application system, N levels are applied as prescribed, fertilizer costs are reduced, and N-loss to the environment is reduced. Basing profitability in terms of yield only, this system is economically feasible. The authors base their economic study on yield only. Other costs, such as the costs of maintaining *Soil Doctor* and training individuals how to operate and care for it are not considered.

Daberkow, Stan G. and William D. McBride. 1998. Adoption of precision agriculture technologies by U.S. corn producers. Precision agriculture: proceedings of the fourth international conference, part B, p. 1821-1831. ASA-CSSA-SSSA, Madison WI. (Return to REFERENCES.)

Objective: The authors present data on the adoption rate of precision agriculture technologies by corn farmers. The analysis provides a description of the socioeconomic profile of adapters, especially early adapters. Key mechanisms and sociological attributes involved in the adoption process are fleshed out using logit analysis.

Methods: A logit analysis is used to describe the sociological profiles of farmers that had adopted precision technologies, specifically grid soil sampling, VRT for lime and fertilizers, and yield monitoring.

Results/Conclusions: Farmers who had adopted precision agriculture technologies tended to be more educated having completed college, and were full-time farmers compared to non-adopters. Debt-to-asset ratios were also larger for adopters. Early adopters also farmed significantly more acreage, were more specialized in producing cash grains, and made more money from corn sales than non-adopters. Logit analysis results indicate that adopters were more likely to keep farm records using computers, were less than 50 yrs of age, relied on consultants for technical advice, and had higher expected corn yields. The authors' variables used to measure risk (debt-asset ratio, crop and income diversity, land ownership) were not significant in the logit analysis. Although farmers from IL, IA, and IN were more likely to have adopted precision agriculture technologies (especially yield monitors), regional variation may have been compromised as data from 16 states (950 different farms) was combined.

Crop: corn, soybean
Technology: yield monitors, VRT
Region: Mid West

Daberkow, Stan G., and William D. McBride. 1998. Socioeconomic profiles of early adopters of precision agriculture technologies. Journal of Agribusiness, 16(2): 151-168. (Return to REFERENCES.)

Objective: To describe the factors influencing technology adoption, and to present data collected by survey illustrating the extent of adoption of precision agriculture technologies by farmers in the United States. A socioeconomic profile of early and late adopters is provided, along with a comparison of farm resource use and allocation differences between adopter and non-adopters. A logit analysis is employed to identify key characteristics related to decisions whether to adopt precision agriculture technologies.

Methods: The author conducts a logit analysis to determine the probability that farmers will adopt precision technology, specifically grid soil sampling, VRT for lime and fertilizers, and yield monitoring.

Results/Conclusion: Farmers who had adopted precision agriculture technologies tended to be more educated having completed college, and were full-time farmers compared to non-adopters. Debt-to-asset ratios were also larger for adopters. Early adopters also farmed significantly more acreage, were more specialized in producing cash grains, and made more money from corn sales than non-adopters. Logit analysis results indicate that adopters were more likely to keep farm records using computers, were less than 50-yrs of age, relied on consultants for technical advice, and had higher expected corn yields. The authors' variables used to measure risk (debt-asset ratio, crop and income diversity, land ownership) were not significant in the logit analysis.

Crop: corn
Technology: precision agriculture/general
Region: United States

Daberkow, Stan G., J. Fernandez-Cornejo, and W.D. McBride. 2000. The role of farm size in the adoption of crop biotechnology and precision agriculture. Selected paper for presentation at the 2000 AAEA meetings, Tampa, FL, July 30-August 2. (Return to REFERENCES.)

Objective: To compare the impact of farm size on adoption rates between genetically modified seeds - a presumed scale-neutral technology - and precision agriculture (PA) - a scale-biased technology. The authors conclude that farm size is positively related to the ability to innovate.

Methods: A Tobit analysis estimated adoption models for genetically modified (GM) seeds and PA. Data was from the USDA's 1998 Agricultural Resource Management Study (ARMS). Variables in the database include farm financial conditions and management history, demographic profiles, and farm management and marketing strategies. Farmers were asked to what extent they employed alternative production strategies, such as GM and PA, in their operations. PA technologies included grid soil sampling, VRT, and yield monitoring. Variables used in the Tobit analysis included a firm's ability to access credit, available human resources/capital, farm location (proximity to agribusiness dealerships, soilscapes, and climactic considerations), labor supply, land tenure, risk preferences, education, and farm structure and size. The dependent variable was the percent of farmland managed using either GE and/or PA technologies. The definition of a "farm" was any business that produced at least $1000 of agricultural goods per calendar year.

Results/Conclusion: For GM seed adoption, farmer education and experience, location in the Heartland region, and farm size were positively related with adoption. Tenure (as ratio of owned to farmed acres) was negatively associated with adoption of GM technology. Credit reserves, and the ability to access money on a loan basis, location in the Heartland region, revenue insurance (a hedge against risk), and farm size were positively related to PA adoption. According to the authors, the ability to access credit depends on land size and tenure, plus other variables. The authors were surprised that education was not strongly associated with PA adoption. However, early adopters rely upon consultants and suppliers as substitutes for personal human capital reserves. The authors found that, in contrast to the current literature on risk and adoption of PA technologies, risk preference measurements (as use of revenue insurance) was positively related to PA adoption. They suggest this indicates early adopters are risk-averse. In sum, the study concludes that a scale-bias exists for both GM and PA technologies, but that the bias level is much greater for PA than GM practices. Likewise, farm size seems to be related to the capacity and propensity to innovate and adopt new technologies.

Crop: any
Technology: PA and genetically modified seeds
Region: Midwest

Doerge, Tom. 1999. Yield monitors create on- and off-farm profit opportunities. Crop Insights, Pioneer International, 9(14), p. 1-4. (Return to REFERENCES.)

Objective: To summarize potential on- and off-farm profit opportunities presented by adoption of yield monitors. The risks associated with the adoption of yield monitor technology are outlined in a unsubstantiated reports analysis. Adoption of yield-monitors is compared to adoption of variable rate technology components.

Methods: The author's discussion is based on personal experience and other refereed sources.

Results/Conclusion: Yield monitoring and mapping provides producers a whole-farm perspective of the overall effects management decisions have on farm operations, whereas variable rate technologies provide a field-level perspective. As such, benefits gained from variable rate technologies are understood best using partial budget analyses. On the other hand, whole-farm or farming systems analysis is more appropriate for appreciating yield-monitoring benefits. Information generated by yield monitoring can be used over several years providing the producer a foundation for long-term strategizing. One problem associated encountered evaluating yield monitor profitability is the subjective nature of the information produced. The bias of the interpreter, the experience level of the producer, and the precision of the map influence conclusions drawn from map interpretations. Benefits from yield monitoring will only be realized when the technology is used concomitantly with other precision agriculture components such as variable rate technologies. Yield monitors presently estimate grain moisture content and yield per acre. Contour maps representing the spatial distribution of these parameters across a field can be produced by the addition of GPS receiver. In turn, this package can be retrofitted to other farm implements such as sprayers and spreaders or planters, or any other field operation. Long-term yield trends can be linked to profit gains or losses within a field. The author cautions those considering adopting yield monitor technology. A producer must be capable of overcoming a learning curve, needs to have the capability of storing, retrieving, and analyzing voluminous amounts of year-to-year production data, and has to be willing to adapt yield monitor technology to other variable rate technologies such as soil fertility and conductivity mapping, soil test lab results, crop scouting, weed mapping, and potentially remote sensing.

Crop: any
Technology: Yield monitors, mapping
Region: corn-belt, Midwest

English, B.C., R.K. Roberts, and S.B. Mahajanashetti. 1999. Spatial break-even variability for variable rate technology adoption. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1633-1642, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To develop a model and provide a methodology for determining the minimum spatial break even variability a producer needs for gains from VRT to outweigh implementation costs. Especially considered are the roles of crop prices, consultant charges, and crop inputs.

Methods: Costs of custom hiring precision farming services was estimated to be \$4.67/acre. The authors used a 30-acre hypothetical field. Grand total for VRT services was \$140.10. Corn prices were assumed to be \$2.65/bu. The authors imagined that two land types – high and low yielding - characterized the field. Returns from uniform and

VRT applications were compared relative to different ratios of low- and high-yielding land types. Yield responses for uniform and VRT treatments were estimated using quadratic functions. Returns from VRT were calculated by adding the yields generated from low- and high-yielding land. Yield was determined as the product of the corn price and the yield of a land area less the product of the yield of the same land area and the nitrogen price. Yields for uniform applications were similarly determined, except that total number of cultivated acres and associated yields were used. When returns from VRT less returns from uniform application methods were greater than the custom service fees for VRT, then the hypothetical farmer was assumed to adopt VRT. This determined spatial break-even variability.

Results/Conclusion: When simulated fields were composed of greater than 30% and less than 85% low-yielding land, returns from VRT were positive. The authors conclude that farmers will benefit from VRT where fields are typified by these low- and high-yielding land distribution ratios. The results are sensitive to changes in corn to nitrogen price ratios. When the nitrogen to corn price ratio is increased by a rise in the price of N, the low-yielding land minimum falls 2 percentage points. When the ratio was increased by a fall in corn prices, the optimal ratio of low- to high-yielding land did not drastically change (<1% high and low-yielding land). An increase of 2 percentage points of the minimum amount of land needed in order for VRT to be profitable was incurred when the nitrogen to corn price ratio decreased when a decrease in N prices was assumed. The authors assumed a VRT service cost of $4.67/acre (or $140.10 for 30-acre, as in their example). If this rate were broken down into a line item budget, perhaps a more detailed economic analysis could be provided. Aside from varying the price of nitrogen in one of their scenarios, there were no other stochastic terms incorporated into the model. Incorporating such variables is beyond the breadth of the report. However, larger, more sophisticated analysis would have to take factors such as time, variable costs, discount rates, market activities, or perhaps even tax incentives in order to better model VRT adoption.

Crop: corn
Technology: VRT
Region: Tennessee

English, Burton C., S.B. Mahajanashetti, and Roland K. Roberts. 1999. Economic and environmental benefits of variable rate application of nitrogen to corn fields: role of variability and weather. Selected paper for the annual meeting of the American Agricultural Economics Association, Nashville, TN, Aug 8-11, 1999. (Return to REFERENCES.)

Objective: By changing weather conditions and spatial variability, the economic viability of VRT is explored. The hypothesis that precision farming provides economic benefits is tested, as well.

Methods: The EPIC crop growth model was calibrated to simulate weather conditions, corn production, and nitrogen-crop responses under three different soil regimes and three rainfall patterns. The simulation included thirty-six 100-acre fields with each with mixed soil profiles. Differences in return from variable rate (VRT) and uniform rate (URT) N application methods were compared. Adoption of VRT was assumed to be 3.00$/acre. Nitrogen and corn costs were \$0.26/lb and \$2.79/bu, respectively.

Results/Conclusion: All but five of the 36 fields showed positive returns using VRT. When rainfall was below average, more fields used VRT. Twenty-two percent of the fields used URT when during average rainfall scenarios. When rainfall was programmed one standard deviation less than expected, three more fields would be managed under VRT. When nitrogen application rates were restricted, returns to fields managed using VRT were greater than those that were not. Nitrogen loss to the environment decreased on all simulated fields with VRT. Rainfall impacts nitrogen loss, carry-over affects, and the presence of soil nitrogen content during crop growth. Although more complex and time consuming, instead of using rainfall averages for an entire seasons, perhaps rainfall variation over an entire season within a field would produce more accurate simulation data that could then be used in a larger models comparing VRT and URT. In addition, spatial variation in terms of elevation could be incorporated into such a simulation program.

Crop: corn
Technology: VRTN, model
Region: Tennessee

English, Burton, Roland Roberts, and David Sleigh. 2000. Spatial distribution of precision farming technologies in Tennessee. Research Report 00-05, Department of Agricultural Economics and Rural Sociology, University of Tennessee, Knoxville, February, 2000. (Return to REFERENCES.)

Objective: To identify the current distribution of precision agriculture technologies used in Tennessee, which crops are commonly managed using precision agriculture technologies, and to describe the adoption trends associated with these use patterns.

Methods: A survey was used to gather information about use of precision agriculture technologies in 95 counties in Tennessee. Precision farming was defined as any technology that aided producers: (1) in the collection of information used to identify field variability, (2) in making decisions about variable fertilizer application rates in a field, and (3) in variable application of fertilizers. Other information collected during the survey included the number of farmers using precision agriculture technologies in each county, the kinds of technology used, the crops and acreage managed by these technologies, and the increase in precision agriculture user-groups between a given time period (1 year).

Results/Conclusion: Survey results indicated that 284 farmers used at least one component of precision farming technology. This is less than 0.5% of all farmers in Tennessee, and slightly more than 1% of the farms with annual incomes more than $10,000. Yield monitors were the most common precision farming technology used by respondents (36% of the 95 counties). Of the counties using yield monitors, 62% used GPS related technologies as well. Grid sampling was practiced at some level by framers in 29% of the counties. Grid sampling was practiced concomitantly with yield monitoring (89%) in counties with yield monitors. Variable rate technology was not as common as yield monitoring and grid sampling activities. Results indicated that farmers in 18% of the counties using precision agriculture technologies practiced variable rate application as well. Precision agriculture technologies were most commonly associated with corn (55,420 acres), followed by soybean (54,050 acres), cotton (18,560 acres), and wheat (21,150 acres). The authors suggest that the number of farmers using precision agriculture-related technology will be 3%, with a total of nearly 8% of total crop farms by 2004 if current adoption rates continue.

Crop: corn
Technology: precision agriculture, general, adoption rates
Region: Tennessee

Fairchild, D., and M. Duffy. 1993. Working group report. *In* Site-specific management for agricultural systems, p. 245-253, ASA/CSSA/SSSA/, Madison, WI. (Return to REFERENCES.)

Objective: To summarize the economic components that should be included in any analysis of new farming technologies, especially those associated with precision agriculture.

Results/Conclusion: There is no empirical data presented in this report, as it is a review. The authors generalize three economic principles to be considered when understanding profitability in the farm context: marginal (unsubstantiated reports) analysis, partial budgets, and whole farm planning. The first analysis examines the point at which the marginal cost of the input equals the marginal revenue. As an example, fertilizer should be applied until the last unit spent returns an additional unit of output. Cost increases and decreases of adopting a new technology need to be itemized. Then, revenue increases and decreases are evaluated. When cost decreases; in addition, revenue increases are greeter than cost increases and decreases in revenue, then the activity is profitable. Whole farm planning analysis should be when a new practice will completely alter the farm structure; for example converting corn fields to fish ponds. Other factors to consider include risk, management skills, time scales, discounting and opportunity costs, human capital, and off-farm costs and benefits.

Crop: na
Technology: economic analysis of new technologies
Region: na

Farm Industry News. 2000. How to access precision agriculture technologies. Internet document, (wysiwyg://3/http://service.industryclick.com/specialsection/story.cfm?voc=agc&id=83) (Return to REFERENCES.)

Objective: This internet document outline a stepwise plan of action for adopting PA technology in today's marketplace.

Results/Conclusion: One of the interviewees concludes that entering the PA technology is difficult since commodity prices are low and producers' investment behavior is geared toward shot term profits. Innovation would have to be in line with cash flow, plans to expand production operations, and changes in overall farm business plans. The interviewee recommends that producers first acquire yield monitors equipped with GPS, followed the next season by a GPS guidance system, then VRT technologies. A scenario is provided describing the above stepwise adoption process. If a corn-soybean producer who farms 2000 acres purchases a yield monitor for $7000, and increases yield by 1 bu/acre by conducting variety comparisons, the investment will be paid off in one season. Other pest or drainage problems might be solved as well, increasing further the benefits.

Crop: mainly corn, soybean
Technology: PA summary
Region: Primarily Cornbelt

Feinerman, Eli, and Eshel Bresler. 1989. Optimization of inputs in a spatially variable natural resource: unconditional vs. conditional analysis. Journal of Environmental Economics and Management, 17: 140-154. (Return to REFERENCES.)

Objective: To expand upon methods used to determine the economic feasibility of spatially variable fields using a stochastic optimization approach. The authors focus on water as a limiting resource in irrigation systems.

Methods: Variables of import in this report are yield, information use, and diminishing returns. The stochastic optimization model assumes that variable parameter estimates are random. Two scenarios are examined within the context of irrigation constrained by a limited water supply: (1) conditional economic optimization, and (2) an unconditional, or "closed-form solution" to the conditional optimization scenario. Scenario 1 assumes that the variables of interest in the model are autocorrelated. In contrast to the unconditional analysis (Scenario 2), the variables of interest are not assumed to be independent of one another, and the probability density functions associated with each parameter estimate are not stationary. Probability distribution functions for scenario 1 are derived from specific points in a field, not from a field average. Actual field measurements are used during the analysis, not generalized probability distribution functions. This effectively reduces the uncertainty caused by stochastic effects correlated with field spatial variations. The probability a producer will use field data information efficiently is thereby increased.

The two scenarios are evaluated in terms of which model best describes efficient use of information by a decision-maker, i.e. a farmer who decides where, when, and what amounts of water should be supplied to a specific area of a field given a set of constraints. A check model was compared to the conditional and unconditional models. It assumed that the producer had perfect information. For the analysis, a hypothetical, spatially variable irrigated field growing corn was used to test the above scenarios. A corn response function from another report was used during trial runs.

Results/Conclusion: Yield variance was less with the conditional model, meaning risk was minimized when information was based on the assumption sample point proximity directly affected the degree to which test values were correlated. Both models were sub-optimal in terms of net returns from water use compared to the check model. The conditional model utility value for water use was 0.5% lower than the check model, whereas the value for the unconditional model was 10% below the control value. The authors conclude that by assuming variable autocorrelation, yield variance is reduced. Reduction of yield variance decreases the riskiness involved in making a decision. According to the authors, the conditional approach optimizes a body of information, and reflects more efficiently a given state of reality during simulation. The question remains for the authors: how much information is enough?
(Return to INTRODUCTION.)

Crop: corn
Technology: VRT-irrigation
Region: Israel

Fiez, Timothy E., Baird C. Miller, and William L. Pan. 1994. Assessment of spatially variable nitrogen fertilizer management in winter wheat. Journal of Production Agriculture 7(1): 86-93. (Return to REFERENCES.)

Objective: To determine the optimal amount of nitrogen needed to produce a unit of grain in a field of variable fertility, and to estimate the economic value of variable rate nitrogen application based on landscape position as a guideline for dividing a field into units of equal fertility.

Methods: Five nitrogen rates (0, 50, 75, 100, and 125 lb. N/acre) were applied over four different topographic profiles (footslope, S-backslope, shoulder, and N-backslope). Treatments were replicated four times at each location using a randomized block design. Soil from each landscape was sampled prior to the experiment. Crop rotations were spring lentils, winter wheat, and spring peas. After harvest, N-loss was determined.

Results/Conclusion: The authors conclude that spatially variable nitrogen recommendations must based on yield potential estimates, the amount of nitrogen needed to produce one unit of grain at optimum yield, and the amounts of residual nitrogen in the soil. The economic benefits of variable rate nitrogen application (VRTN) occur by limiting areas of over- and under-fertilization in a field. The scale of these benefits depends on the actual amounts of misapplied fertilizer during a single-rate treatment, and the yield responses attributed to misapplication. Three important factors have to be considered. Information about yield potential, unit nitrogen requirement, residual N and N mineralization are needed for accurate recommendations. Two, fields with highly variable fertility mosaics should benefit more from VRTN since the probability that under- or over-fertilization is greater with uniform N application practices. Last, fields where yields slightly decrease or increase following N over-application or when yields fall dramatically after N under-application will benefit most from VRTN. The authors provide a simple unsubstantiated reports analysis in their report. However, important factors such as human capital, costs of information collection and management, fixed and variable costs, and opportunity costs were not identified. It is unknown whether the figures used to compare the treatments included these components. (Return to Table 9.)

Crop: beans, wheat
Technology: VRTN
Region: Washington

Finck, Charlene. 1998. Precision can pay its way. Farm Journal, Mid-January 1998, p. 10-13. (Return to REFERENCES.)

Objective: To summarize the results of an ongoing study examining the profitability of site-specific farming.

Methods: A 1,300-acre farm was divided into three primary management zones based on soil type. A uniform application rate served as the control. The second treatment integrated site-specific management strategies with manual application techniques. The last treatment used GPS integrated with site-specific hardware and software to automatically distribute fertilizer at prescribed rates according to soil fertility. Maps were used in the second and third treatments. Detailed partial budgets were used to evaluate the profitability of VRT.

Results/Conclusion: Input reallocation was primarily responsible for increased revenue in both variable rate treatments. Matching inputs to soil types weather-proofed lighter soils for high temperatures and drought, and prepared the more fertile soils to produce above estimated yield potentials. However, yield increases were more consistent with lighter soils than they were for heavier soils. Heavy soils covered 91% of the field. There were little to no yield increases in these zones. However, savings from applying less fertilizer to the high fertility zones generated positive returns.

Table 19. Reported net returns comparing GPS and manual application strategies.

Treatment			
	Standard	**Manual**	**GPS**
Average net return (3-yrs, corn/soybean, $/acre)	$305.43	$322.69	$319.34
Advantage over standard rate ($/acre)		$17.26*	$13.91**
Average net return (3-yrs, corn, $/acre)	$279.45	$298.57	$299.10
Advantage over standard rate (corn, $/acre)		$19.12*	$19.65*
Average 3-year corn yield (bu/acre)	151	163	166
Corn yield advantage over standard rate (bu/acre)		12*	15*
Average 3-year soybean yield (bu/acre)	53	55	54
Annual Technology and Equipment Costs			
	Corn		Soybean
Manual treatment	$10.03/acre		$1.83/acre
GPS treatment	$18.94/acre		$3.82/acre

Yield monitor alone = $1.33/acre
Yield monitor with GPS = $3.32/acre
*Significant at 5% level.
**Significant at 10% level

(RETURN TO INTRODUCTION, Table Listing, or Table 9.)

Crop: corn, soybean
Technology: VRT
Region: Illinois

Finck, Charlene. 1997. The learning curve. Farm Journal, Mid-February, 1997, p. 6-7. (Return to REFERENCES.)

Objective: To describe a case study situation about the "learning curves" associated with the adoption of new technologies into extant farming operations.

Methods: The author uses farm manager testimonial recounting their experience learning how to use GPS guidance and maps during variable rate fertilizer application.

Results/Conclusion: According to the operator, it took one season to "work out the bugs" of the entire system. The system included GPS guidance, a laptop computer, and mapping software. Once problems were worked out, the operator felt empowered knowing that unfamiliar, "high-tech" hardware and software could be apprehended then applied to his operations. Increased returns from the integrated GPS-mapping system further reaffirmed the operator's enthusiasm for the new technology.

Crop: corn, soybeans
Technology: VRT
Region: Illinois

Fixen, P.E., and H.F. Reetz, Jr. 1995. Site-specific soil test interpretation incorporating soil and farmer characteristics. Site-specific management for agricultural systems: proceedings from the 2nd international conference, March 27-30, Minneapolis, MN, p. 731-743. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To provide an alternative to methods conventionally used to interpret soil maps. The author argues that fertilizer recommendation rates need to be site (farm)-specific, rather than general (i.e. recommendation rates provided by extension services). A software program that personalizes soil profiles by focusing on optimization of long-term profitability is introduced.

Methods: The model used yield and soil test data from an ongoing USDA corn and soybean production study. Grid sample data was used to make soil maps representing four soil types. Soil test and pH varied considerably across soil types.

Results/Conclusion: By dividing the average historical yield for each soil type by the predicted relative yields generated soil yield potentials. The authors found that whole-field management practices had decreased soil fertility of the potentially most productive soils. This resulted in the most productive soils yielding no more than the least productive soils in the field. The authors conclude that site-specific interpretation must include soil characteristics, and farmer management preferences based on management history. Additionally, site-specific management may increase yield variability by augmenting yield of already highly productive areas. Lastly, information feedback and data management will improve the accuracy of site-specific management information, hence its efficacy over time. No enterprise budget was presented in the analysis. Although probably justified by yield data, inclusion of information such as soil test costs and estimated returns from implementing prescriptive measures from this information would strengthen the authors' argument that conventional management methods had decreased soil productivity.

Crop: corn, soybean
Technology: VRT-fertilizer N, P
Region: Iowa

Forcella, Frank. 1993. Value of managing within-field variability. Soil specific crop management: proceedings of the 1st workshop, Madison, WI, p. 125-132. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To highlight the basic concepts influencing the decision whether of not site-specific management of within-field variability is cost effective.

Methods: Eleven 10 ha hypothetical fields were programmed to have varying degrees of field variability ("soil characteristics"). Each field was divided into 10 sections. Sections either had one soil characteristic, while other grids did not. Binary codes were used to distinguish these differences. From here, a field variability index was made. Fields with more variability required different amounts of N fertilizer. Misapplication costs were calculated. Corn yield response to N fertilizer was assumed to be linear, with a plateau at 100-kg/ha.

Results/Conclusion: VRT is most effective when soil profile variability is greatest in fields. The type of fertilizer applied to fields will also determine cost effectiveness of soil specific management. For example, if inexpensive fertilizers are used, it may be more cost effective to apply the material uniformly throughout the entire field instead of paying for information yielding field variability and extra costs associated with variable application. According to the author, the converse holds true with expensive compounds. Variable application of expensive materials may be economically justified after information collection and application costs are considered. This simplistic model could be improved by adding additional variables. The author states that one of the shortcomings of the model is that it cannot consider externalities associated with fertilizer or pesticide runoff. Nor does it consider information collection costs, costs that might be saved because of carryover effects, or costs cleared by positive returns from production.

Crop: all
Technology: VRT, modeling
Region: any

Fountas, Spyridon. 1998. Market research on the views and perceptions of farmers about the role of crop management within precision farming. Master of Science Thesis. Silsoe College, Cranfield University.
http://www.silsoe.cranfield.ac.uk/cpf/papers/spyridon_Fountas/index.htm
(Return to REFERENCES.)

Objective: To understand farmer perceptions of the role of crop management within precision agriculture. Producers using and not using precision farming technologies were interviewed. As this is a demographic profile of user-groups, no formal economics on the profitability of specific PA technologies is provided.

Methods: Postal questionnaires were mailed to producers. General descriptive statistics report the results.

Results/Conclusion: Survey results indicated that 15% of the respondents used some combination of precision agriculture technologies. Users were satisfied in terms of their expectations about the technology being met. Reasons why producers had not adopted PA techniques included the high investment costs, variable results, and minimal agronomic support and technical advice. Consumer groups, agro-machinery suppliers and manufactures, and PA experts would accept involvement of an agrochemical company in the development and promotion of PA technologies.

Crop: mixed
Technology: PA summary, demographic profiling
Region: UK

Godwin, R.J., I.T. James, J.P. Welsh, and R. Earl. 1999. Managing spatially variable nitrogen – a practical approach. Presented at the Annual ASEA meeting, Paper N^{o} 99-1142, 2950 Niles Road, St. Joseph, MI, 49058-9659, USA. (Return to REFERENCES or Table 9.)

Objective: To evaluate two methods to determine VRT-N application rates. The first method produced site-specific yield response functions, the second approach employed historical field data to determine optimal N rates. The goal of these objectives is to find the optimal N rates for low- and high-yielding portions of fields. This would entail increasing N rates in high-fertility zones, while, decreasing rates in low-fertility zones. The authors conduct a rudimentary partial budget analysis to determine the economic feasibility of each approach.

Methods: Three sites, all with a cropping history of continuous wheat-barley and all with different soil profile characteristics were used in the experiment. Yield maps spanning three years referenced each site, and macro- and micro- soil nutrient levels were determined to identify soil fertility variability. Two soil series characterized the first site, while three series characterized the other sites. An experimental design was developed that could be replicated at a low cost by farmers (as opposed to randomized, small blocks). Fields were dived into a series of strips with widths that matched farm machinery. Widths at each site varied since producer equipment varied. Two treatments were compared:" uniform ((URT) and variable (VRT) N rate treatments. For URTs, different N rates were applied evenly along each strip. For VRT treatments, low, medium, and high fertility zones were identified in each strip. High-yield zones received 30% more N than average-fertility zones, while low-fertility zones received 30% less than average-fertility zones. Rates were based on historic yields. A response function was used to determine the most economic rate of N (MERN) and the N rate for maximum yield (NMAX).

Results/Conclusion: As expected, results varied between sites, and maximum yield was obtained using different N rates based on soil fertility values within sites. The authors attribute variability of net returns to climactic conditions as well. Economic returns between all sites were superior to URT treatments, range 5 to £13/ha.

Crop: wheat, barley
Technology: VRT-N
Region: UK

Griffin, Terry, Caleb Oriade, and Carl Dillon. 1999. The economic status of precision farming in Arkansas. Department of Agricultural Economics, University of Arkansas, Fayetteville, 1999. (Return to REFERENCES.)

Objective: The authors discuss the factors influencing the adoption rate of precision agriculture in Arkansas in lieu of returns generated by precision agriculture practices.

Methods: Arkansas agricultural extension agents implemented a survey tool to determine the extent to which Arkansas farmers had adopted precision farming. A case study is presented in the report profiling precision farming in Arkansas. An enterprise budgeting technique was used to determine the profitability of precision farming in the case study. The case farm owns combines equipped with yield mapping equipment, yield monitors, on-board DGPS systems, and moisture monitors. The entire farm had been mapped prior to the study. Grid based soil sampling was the preferred soil testing method. Yield and returns from the farm used in the case study was compared to statewide yield averages for soybean and rice.

Table 20. Survey results of PA adoption rates by Arkansas farmers.

1998 Survey	Rice	Soybean	Cotton	Corn/Wheat
%Farmers using precision farming technology	3-5%	2%	1-2%	3-5%
%acreage managed under precision farming	1%	<1%	<1%	0.1-0.5%
Three leading inputs precisely managed*	1. Fertilizer 2. Lime/sulfur 3. Drainage	1. Fertilizer 2. Lime/sulfur 3. Drainage	1. Lime/sulfur 2. Fertilizer 3. Drainage	1. Drainage 2. Lime/sulfur 3. Fertilizer
Common precision farming practices	1. Grid sampling 2. Yield monitoring 3. VRT**	1. Grid sampling 2. Yield monitoring 3. VRT**	1. Grid sampling 2. Variable rate application	1. Yield monitoring 2. Grid sampling 3. Variable rate application
Estimated time for:				
10% adoption	3 years	4 years	2 years	2 years
20% adoption	8 years	10 years	10 years	5 years
30% adoption	15 years	15 years	Never	10 years

*Descending order of importance.
**Variable rate fertilizing.

(Return to Table Listing.)

Yield and returns for the case farm outperformed the average stateside farm yields across the three-year time period. However, yield and returns were higher on the case farm two years before precision farming technologies were implemented. Operators attributed lower yield and return to poor growing conditions. Similar trends were evident examining state average production data. The authors conclude there is no evidence to support the perception that precision farming reduces risk. The authors noted difficulties evaluating the economic potential of precision farming with on-farm data. Farm managers will commit all their acreage to either whole-field or precision management strategies. As such, precision farming can only justifiably be analyzed across time. Whereas the operators held weather conditions responsible for reduced low yields following adoption of precision farming, the authors suggest these reductions might be attributable to learning curve paths. The authors suggest that unlike farmers in the Midwest where adoption of precision farming is supported by service dealerships, adoption of precision farming by Arkansas producers is mainly driven by self-motivation.

Crop: soybean, rice
Technology: precision agriculture
Region: Arkansas

Griffin, T.W., J.S. Popp, and D.V. Buland. 2000. Economics of variable rate applications of phosphorous on a rice and soybean rotation in Arkansas. Proceedings of the 5th International Conference on Precision Agriculture and Other Resource

Management, July 16-19, 2000, Radisson Hotel South, Bloomington, Minnesota, USA. (Return to REFERENCES.)

Objective: To determine the relation between phosphorous and yield on four soils in Arkansas, and evaluate the profitability of VRT-P treatments on a rice-soybean rotation system. Conditions when VRT-P application is successful are summarized.

Methods: An EPIC-derived model simulated rice-soybean crop yields over a thirty-year period. Simulated data (4000-plus data points) was modeled using dynamic optimization to represent management choices, decisions, and applications over a ten-year planning period. Profitability (as input costs subtracted from gross revenue) was incorporated into the model. Enterprise budgets provided investment cost estimations. Three uniform application rates (URT) were compared with VRT rates. Three URT-phosphorous rates were determined according to soil characteristics. Four soil types characterized test fields. Three soils were silt-loam composites, while the remaining type was clay.

Results/Conclusion: Variable rate P application was more profitable than URT treatments when soil was 50 to 75% silt-loam composition. When the proportion of the field was between 3 and 97% clay, VRT was more profitable than URT treatments. In fields where mixture of clay and silt-loam predominated, returns from VRT were $200/acre over a ten-year planning cycle. In general, VRT was not a desirable management strategy when a single soil type dominated the simulation field. URT was more profitable in fields characterized by homogenous soil types, especially silt-loam composites. However, sub-optimal P rates adversely affected yield. For example, when P rates determined for silt-loam soils were applied to clay soils, rice and soybean yields dramatically decreased.

Crop: rice, soybean
Technology: VRT-P
Region: Arkansas

Hammond, M.W., and D.J. Mulla. 1988. Development of management maps for spatially variable soil fertility. Proceedings of the 39th Annual Far West Regional Fertilizer Conference, Bozeman, Montana, July 11-13, 1988. (Return to REFERENCES.)

Objective: To develop fertility management zone maps by combining information from P and K soil tests. Quantitative accuracy of management zones derived from different soil sampling densities was determined. A rough partial budget evaluating the economic feasibility of mapping and sampling methods was conducted.

Methods: Soil samples were taken at 100, 200, and 400-ft intervals. Maps of fertility management zones were created using the data. Three fertility categories were used: low, medium, and high. Cut-off levels for map contours were based on regional fertilizer recommendation rates for potatoes. Fertilizer rates for management zones were based on the average of the soil test result for that management zone, published guidelines, and personal experience. Fertilizer blends including N, P, K, S, and Zn were applied to each zone accordingly. A crude partial budget evaluated the profitability of these management combinations.

Results/Conclusion: Although the conventional, uniform application strategy cost less than the variable application treatment ($13,300 and $13,500, respectively), it was inefficient compared to the variable rate strategy since it over-fertilized 45% of the 139-acre field, and under-fertilized 8% of it. In terms of net returns, potato yields from this trial reportedly covered the costs of uniform and variable rate fertilizer treatments.

Crop: potato
Technology: VRT, mapping
Region: Montana

Hammond, Max Ward. 1993. Cost analysis of variable fertility management of phosphorus and potassium for potato production in Central Washington. *In* Site-specific management for agricultural systems, p. 213-219, ASA/CSSA/SSSA/, Madison, WI. (Return to REFERENCES or Table 9.)

Objective: To investigate the economic efficiency of application costs associated with variable rate management strategies.

Methods: Soil test data (K and P) was used to generate fertility management maps representing five zones. Three zones were used in the study. Variable fertilizer rates were applied to management zones after recommendation rates bases on test values were determined. Applications for conventional whole-field management (control) treatments were based on the average of the soil test results. Input costs for each strategy were recorded. After harvest, yield revenue was compared with input costs.

Results/Conclusion: Production costs increased under the variable rate management strategy, but not significantly. Cost increase was due to grid sampling, sample analysis and data management. The author notes that by increasing crop grade, benefits of variable rate strategies might outweigh implementation costs. Potato yields increased 1-2 toms/acre, resulting in net returns of $75-150/acre. When the overall potato grade is improved, $10-15/acre revenue was realized. Where fields average 30 tons/acre, this translates into increased revenues of $300-450/acre.

Crop: potato
Technology: VRT
Region: Colorado

Haneklaus, S., D. Schroeder, and E. Schnug. 1999. Decision making strategies for fertilizer use in precision agriculture. Precision agriculture: proceedings of the 4th

international conference, July 19-22, p. 1757-1765, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To evaluate different decision-making processes governing variable fertilizer application.

Methods: Soil N and P content were measured. Additionally, the minimal amount of N available to plants was determined. Plant N content was determined by Kjeldahl analysis. Results from geostatistical surveys were used to produce digitized soil maps.

Results/Conclusion: The authors conclude that in order to accurately describe the distribution of P, N, and other essential plant nutrients, $10m^2$ blocks (!) are needed as sample sites. Furthermore, these smaller block units need to be georeferenced to generate maps that accurately represent field heterogeneity. Georeferencing plots also allows for temporal analysis. A cursory economic analysis suggests that VRT reduces kilograms of fertilizer-P applied (an environmental benefit) and fertilizer expenses (an increase in profits). The table presenting the economic figures is not in partial budget form, as it does not consider additional costs associated with VRT.

Crop: oats
Technology: VRTN
Region: Europe

Harper, Jayson K., M. Edward Rister, James W. Mjelde, Bastiaan M. Drees, and Michael O. Way. 1990. Factors influencing the adoption of insect management technology. American Journal of Agricultural Economics 72: 997-1005. (Return to REFERENCES.)

Objective: To study the adoption process of a capital technology, and identify the variables influencing decisions to apply pesticides.

Methods: A logit model is used to specify adoption patterns of rice producers faced with two management options targeting pest control - spraying or use of a sweep net. Data were collected using surveys. Model variables included age, education level, farm size and complexity, and firm characteristics, applied N fertilizer, adjacent crops, planting date, and participation at extension fairs.

Results/Conclusion: The decision whether to adopt sweep net technology was dependent upon the farm manager's education level, the amount of neighboring land in pasture, the proportion of rice acreage planted to other rice varieties, farm location (in Texas), and extension fair attendance. Education was negatively related to adoption of sweep nets. More educated managers were less likely to adopt this technology. The authors suggest that individuals with higher education see other aspects of their operations more important than spending time using a sweep net. Farmers were also more likely to adopt this technology where damaging pests were more abundant. Those who attended extension fairs were more likely to use sweep net technology. Spraying for pests was significantly associated with more variables in the model (13 of 19) than the model used to analyze sweep net adoption (4). Older farm managers were more likely to spray for pests. Likewise, operations with larger fields employed spray management as well.

Crop: rice
Technology: pesticide, technology adoption
Region: Texas

Hayes, J.C., A. Overton, and J.W. Price. 1994. Feasibility of site-specific nutrient and pesticide applications. Environmentally sound agriculture: Proceedings of the 2nd conference, April 20-22, 1994. Orlando, FL, St. Joseph, MI. (Return to REFERENCES.)

Objective: This report discusses methods whereby the decision whether to use certain components of precision agriculture, specifically variable rate fertilizer application, can be rationally made. Specifically mentioned is the use of GPS/GIS technologies.

Methods: Soil type variability was determined on a field traditionally used to produce corn. Historical yields associated with the soil types were retrieved. Corn nutrient requirements were estimated based on data collected by the university extension service. Local nitrogen fertilizer costs were used in a partial budget analysis. Nitrogen application rates were estimated for each soil type. Four scenarios were simulated: (1) variable rate fertilizer application, (2) N applied at the rate expected to produce the highest yield, (3) N applied using a weighted average, and (4) a weighted average based on low-yielding portions of the field. A crude partial budget was used to evaluate the profitability of site-specific fertilizer management strategies.

Results/Conclusion: Nitrogen costs for scenario 1 ($8043) were lower than they were for scenario 2 ($8980) and scenario 3 ($8051). Nitrogen costs for scenario 4 was lowest compared to the other scenarios ($6317). The authors rejected results from scenario four, as the parameters from which they were derived were entirely hypothetical. The authors' caution that differences in returns does not necessarily correlate with the management strategy implemented. (Return to Table 9.)

Crop: corn
Technology: VRT
Region: South Carolina

Heiniger, R.W., and A.M. Meijer. 2000. Why variable rate application of lime has increased grower profits and acceptance of precision agriculture in the southeast. Proceedings of the 5th International Conference on Precision Agriculture and Other Resource Management, July 16-19, 2000, Radisson Hotel South, Bloomington, Minnesota, USA. (Return to REFERENCES or Table 9.).)

Objective: To determine the lime rates needed for variable rate lime application using grid-sampling techniques, and determining whether this practice was profitable. The authors ask whether profitability improvements are due to decreased inputs (lime), increased yields, or both of these factors. To do so, they characterized within-field pH variability using grid soil testing. The authors provide a partial budget analysis examining the economic feasibility of VRT-lime for corn production in Southeastern U.S.

Methods: Soil samples were collected from 111 fields that had been limed using variable rate technology (1997-ha, total). One hectare, rectangular grids were used in both coastal-plain and tide water sites to determine soil pH values. Corn yield response was determined based on grid test results. A simple partial budget was constructed to determine VRT-pH profitability. VRT application charges were $27.50/ton and uniform charges were $25.00/ton. Grid soil sampling costs (dealership prices) were $7.00/acre. Uniform soil sampling costs were priced at $2.59/acre. Costs were not amortized.

Results/Conclusion: VRT-pH profitability was different for coastal and tidal regions. Optimal pH levels were generally lower in tidal than coastal regions. In the coastal plain region, VRT adjusted costs were $36.14, while adjusted costs for uniform lime were $39.04. In the tidal region, adjusted VTR costs were $26.74, whereas adjusted costs for uniform application were $20.08. The authors conclude when field pH is spatially variable, uniform testing will over- or underestimate pH values, hence application rates. Secondly, when the average field pH decreases in relation to the target pH, differences in lime requirement estimates increases between uniform and grid sampling techniques. This translates into savings when application rates are based on grid-sampled results. VRT-pH was successful in coastal plain regions since there was a reduction in lime applied to fields which helped pay for variable application costs. Variable rate application costs become similar to conventional application costs. Estimated yield also increased since appropriate pH levels were applied to site-specific problem areas. In the tidal region, higher pH levels required more lime and increased costs associated with grid sampling and VRT application. The authors cite three key factors related to the success of VRT liming. VRT will be profitable when: (1) filed average values of the parameters tested are significantly less than target values, (2) there is a strong relation between crop yield and then parameters being tested, and (3) there exists a penalty (in terms of yield and/or dollars) for both under- and over-application of an input.

Crop: corn
Technology: VRT-pH
Region: Southeast

Heisel, T., and S. Christensen. 1999. A digital camera system for weed detection. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1569-1577, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To describe a digital camera system that can automatically identify weed problem areas in a field, then based on the information provide recommendations as to what course of action (i.e. where pesticide should be sprayed, and at what rate) should be taken.

Methods: Three control sites were established. In each site, a color camera was installed. The camera was equipped with filters sensitive to different light wavelengths. Weed reflectance is a different frequency than crop reflectance. Cameras were attached to computers that estimated weed densities in fields. Computers were attached to a GPS system.

Results/Conclusion: The apparatus provided an acceptable estimate of weed leaf area per meter compared to manual leaf area measurements. However, the camera system can count and process weed data much more rapidly than the conventional, manual method at a speed of 45 km/hour. The authors suggest that this technology would be cost-effective when used with high valued crops. They also imply that pesticide use can be reduced with this technology. Unfortunately, although some economic factors are considered in the report, they are only stated or implied. Implementation costs, operating costs, and other costs associated with training or maintenance of the equipment are not considered.

Crop: wheat
Technology: VRT-pesticide
Region: Australia

Henessy, David A., Bruce A. Babcock, and Timothy E. Fiez. 1996. Effects of site-specific management on the application of agricultural inputs. Working paper 96-WP 156, March 1996. Center for Agricultural and Rural Development, Iowa State University, Ames IA, 50011-1070. (Return to REFERENCES.)

Objective: To develop a crop production model incorporating variability when soil-stored and applied nutrients are cumulative. Production under uncertainty (zero knowledge) and known fertility variability are examined. Under which scenarios variable rate or conventional, uniform fertilizer application programs are suitable is explored.

Methods: Key variables in the model developed by the authors include soil fertility (classified as random), fertilization rate applied by the producer, fertilizer costs, and crop price. Land is assumed to be uniform, except for spatial fertility variability. The production function was assumed to be applicable to all pints on the land surface. Data analyzed using their model was taken from Fiez et al., 1993. Different application rates were 0, 50, 75, 100, and 125 lb/acre. Landscape positions, such as backslope, shoulder, north backslope, and footslope were considered. Wheat price was $3.50 bu/acre. Applied N was assumed to be $.31/lb. Carryover effects were incorporated into the analysis.

Results/Conclusion: Results suggest that site-specific information is a low-value commodity. Although the information generated from site-specific tests have a positive value, the connection between this information, and production and profit are not yet clear. In their study, returns from VRT did not outweigh implementation costs. The authors conclude that there will be little incentive for producers to adopt variable rate technology in its current state: high costs and unreliable, inconsistent results that are often complicated with individual risk preferences.

Crop: wheat
Technology: VTR
Region: Iowa

Hennessey, David, and Bruce Babcock. 1998. Information, flexibility, and value added. Information Economics and Policy, 10:431-449. (Return to REFERENCES.)

Objective: The primary objective of this report is to investigate the complex effects of information upon the firm. A distinction is drawn between uncertainty and known variability, and how these two factors influence the quality of information, and its impact on the firm. Precision agriculture is mentioned briefly by the authors as an example.

Methods: A spatial econometric approach is used to assess the value of information and its relation to revenue generation, and to understand the mechanisms influencing the change from uncertainty to know variability (i.e. probability). By understanding economic decision-making processes under uncertain circumstances and circumstances describable by probability distributions, a clear definition of the economic effects of this shift from the "unknown-unimaginable" to the "probable-deterministic" can be formed. To do this, the authors construct a series of decision functions active in different environments. These functions are associated with outcomes that are realized by choices acted upon by agents who are assumed to be profit-maximizing individuals. Choice and action for agents are assumed exist as a complex between individual preference profiles and different environments differentiated by degrees of spatial dispersion. Spatial dispersion simply assumes that certain choices associated with an outcome (i.e. a technology) have singular variances, or probabilities of occurring or succeeding. Spatial heterogeneity is learned by trial and error. The value of moving towards known variability increases concomitantly with increases in spatial variability. In short, the authors suggest that farmers who use excessive amounts of inputs as a hedge against uncertainty will decrease mean input use upon adoption of site-specific management practices since knowledge about spatial variability is known to some degree.

Crop: any
Technology: precision agriculture, risk, adoption
Region: any

Hertz, Chad A. 1994. An economic evaluation of variable rate phosphorous and potassium fertilizer application in continuous corn. M.S. Thesis, Department of Agricultural Economics, University of Illinois, Urbana-Champaign. (Return to REFERENCES.)

Objective: To identify the conditions which affect variable and uniform rate fertilizer application profitability in terms of field conditions, fertilizer recommendation guidelines, agronomic assumptions, and sampling densities. Economic returns from variable and uniform rate applications are quantified under different levels of soil fertility. The impact of variable rate applications is contrasted with alliterative recommendations of guiding uniform fertilization rates to determine how best to estimate which application method is economically feasible given certain field conditions.

Methods: Expected marginal revenues from variable rate fertilizer application are compared to uniform rate application. Example fields were generated to evaluate the model. Data included field situations categorized as having low, medium, and high initial fertility conditions in areas across the field. Fertility zones density varied throughout the field as low, medium, or high levels of variance. Agronomic and economic rule based fertilization recommendations were compared to a conventional, uniform application strategy. An extension manual was used to estimate fertilizer application recommendations for the uniform and agronomic rule based recommendations. Different soil sampling intensities were compared as well. The final simulated model was tested using data from three farms.

Results/Conclusion: Returns from variable rate application were superior to uniform rate applications. However, mapping costs, soil sampling costs, and variable application costs were not included in the partial budget analysis. As spatial variability of fertility increases, returns from variable rate treatments increased.

Crop: corn
Technology: VRT-P, K
Region: Illinois

Hertz, Chad A., and John D. Hibbard. 1993. A preliminary assessment of the economics of variable rate technology for applying phosphorous and potassium in corn production. Farm Economics 93-14, Department of Agricultural Economics, University of Illinois, Champaign, Urbana. (Return to REFERENCES.)

Objective: To examine the total costs and capabilities of variable rate technology for phosphorous and potassium fertilizers.

Methods: The authors use personal experience and results from other VRT research to describe the current state of the technology, what considerations a producers has to keep in mind when deciding whether to adopt one or more of the components, and what the costs and benefits associated with VRT are. Actual data from original research provide a foundation for a simulated comparison between conventional, uniform and variable rate fertilizer application strategies for P and K. Soil tests were conducted on a 40-acre field using 16 x 16-ft grids, yielding 253 soil samples. During the simulation, three grid-sampling sizes were compared, with a commercial grid size of 2.5 acres. The other sampling sizes were 10 and 0.625-acre grids. Fertilizer rate recommendations were based on yield goals, soil fertility results and the reference map, and an extension publication explaining potential yield-P, K soil fertility relations. Rates for uniform fertilizer applications were determined as a field-wide average of soil test values, and additional aforementioned information sources. For variable rate treatments, applied rates were based on soil test values associated with a particular grid. A partial budget including a long-term net present value framework is included in the analysis.

Results/Conclusion: Although yields were higher for the 10-acre and 0.625-acre grid sizes, net returns/acre were highest for the uniform application strategy ($92.30). The long-term net present value over a 24-year period was also highest for the conventional treatment ($959.84/acre, as opposed to the best VRT treatment, a 10-acre grid sampling size - $956.35/acre). The smaller the grid sampling size, the more expensive soil tests and analyses were. The authors conclude cautioning that these results could be misleading, and that they need to be carefully interpreted. First, these results are generated from data representing one field. Field-to-field variation undoubtedly exists, and initial condition of a field will influence the results of any sensitivity analysis. Secondly, the degree of spatial variability affects the outcome of partial budget analyses. Optimal ratios of low- and high-yielding soils may exist. Variable rate practices may be more feasible on land that has fertility mixes ranging from 20 to 80% low-fertility soils. Third, the present state of farm implements has not caught up with the precision of the tools available to determine field spatial variability. Computer software and hardware have outpaced variable rate applicator technology to date, economically and technologically. Fourth, model outcomes are dependent upon response functions. Response functions, too, are variable from field to field, region to region and year to year.

Crop: corn
Technology: VRT
Region: Illinois

Hollands, K.R. 1996. Relationship between nitrogen and topography. Precision agriculture: proceedings of the 3rd international conference, June 23-26, Minneapolis, MN, p.3-12. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To determine how well N levels corresponded with topological variations, and to develop a map to be used during N application based on these findings.

Methods: Soil sampling was conducted in tandem with elevation determinations. This information was overlaid yielding a map that included information about the spread of field nutrients, and the topography of the field. Correlation between N levels and field high and low points were attempted. Without GPS, soil sampling cost $12/acre. With GPS, soil sampling was $19/acre, but these results were more accurate.

Results/Conclusions: Results of this study are graphically presented. Six maps indicate results of soil testing coupled with GPS, topography maps, and N spread overlaid on top of elevation points. The author states that although the methods used accurately determined the spread of N in relation to field elevations, the technique alone is probably not cost effective. However, a schedule (not detailed) how maps generated using this technology might be useful over a three to four year period is presented. The author concludes that the monetary costs of developing topological maps and software to read them into spreaders would outweigh the costs of repeated grid soil sampling. Unfortunately, no data was available to support this conclusion. Although the author included the costs of soil sampling with and without GPS, other costs such as the use of laser equipment used to take elevation readings, fertilizer costs, costs of delineating grids, and consulting fees were not included. A budget would have been useful. In it estimated yields and projected returns could have been presented.

Crop: sugar beets
Technology: VRTN, Nitrogen, map making, GPS
Region: Minnesota

Hornbaker, Robert H., Roderick M. Rejesus, and Gary D. Schnitkey. 2000. Development and validation of a variable rate nitrogen program in Central Illinois. Proceedings of the 5th International Conference on Precision Agriculture and Other Resource Management, July 16-19, 2000, Radisson Hotel South, Bloomington, Minnesota, USA. (Return to REFERENCES.)

Objective: The three main objectives of the report are: (1) to devise a method for implementing VRT-N programs based on historic and soil potential yields, (2) to develop a validation protocol to determine whether optimal N rates are appropriate, and (3) to conduct a feasibility study examining the economic implications of optimal N application strategies as determined by the validation procedure.

Methods: The authors modify an equation furnished by the 1999 Illinois Agronomy Handbook that determines variable N application rates based on soil fertility and yield goal. The modification incorporates a risk-averse variable, site-specific, spatial components (yield, soil type, the number of unique sites as *x*,*y* coordinates), time (a five-year production cycle is assumed), and climactic variables. A "validation procedure" was inserted into the model where 60 100 x 100 ft. blocks are randomly selected. One-third of the plots receives 30% less N than the recommended rate, another third receives 30% more N than the recommended rate, and the remaining third receives the recommended N rate. Results were kriged in 20 x 20 intervals. Variables of interest were N rate, yield, and soil information.

Results/Conclusion: The experiment yielded mixed and unexpected results. The authors conclude that the results do not contribute to the improvement of the application rule since the 30%-low and 30%-high N application rates produced significantly more corn than plots that received standard application rates. The authors support the currently accepted notion that different soil types may require different N rates.

Crop: corn
Technology: VRT-N
Region: Illinois

Hoskinson, Reed L., and J. Richard Hess. 1999. Using the decision support system for agriculture (DSS4AG) for wheat fertilization. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1797-1806, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The authors discuss three different knowledge systems that influence agricultural decisions - the farmer-based system, the scientific system, and the cognitive information knowledge system, or new technologies such as GPS or computer modeling applications. The authors attempt to integrate these knowledge domains into a comprehensive system. The possibility of applying computer learning algorithms (artificial intelligence, AI) is entertained since voluminous amounts of data are currently available.

Methods: An expert system, DSS4Ag, was programmed to generate an algorithm for determining appropriate variable rates of multiple fertilizers on a 135-acre field. Soil nutrient and yield maps, market prices were model inputs. The field was divided into control and experimental plots (12 blocks, total) where DSS4Ag and control (conventional) fertilizer rates were applied. Each block was 11 acres. Yield monitors measured harvested wheat for each block.

Results/Conclusion: Fertilization recommendations produced by the expert system recommendations generated savings of \$13.72 acre $^{-1}$ compared to uniform application (control) rates. Treatment blocks yielded less biomass. The authors suggest that this is advantageous since less time is required to decompose the compost materials. The economic forecast data indicated that wheat market prices were \$3.35 acre $^{-1}$. The sales loss using the expert system was \$8.38 acre $^{-1}$, but with returns from fertilizer saving, a net benefit of \$5.34 acre $^{-1}$ was achieved. The expert system in question could be compared with other methods used to extrapolate variable fertilizer application rates. Additionally, the model only focused on two variables. Other multivariate, dynamic optimization models might produce more a more accurate representation of spatial heterogeneity.

Crop: potato, wheat
Technology: modeling, VRT
Region: Idaho

Isik, Murat, Madhu Khanna, and Alex Winter-Nelson. 1999. Investment in site-specific crop management under uncertainty. Paper presented at the Annual Meeting of American Agricultural Economics Association, August 8-11, 1999, Nashville, Tennessee. (Return to REFERENCES.)

Objective: To examine the importance of sinking fund costs, uncertainty in returns, and elasticity in investment timing on producers' decision to adopt variable rate technologies. The decision-making process is framed in the context of uncertainty and irreversibility, and the assumption that field spatial variability affects crop yield.

Methods: A behavioral model is developed, followed by an analysis and summary of findings. It is assumed that the producer is a profit-maximizing individual operating a field of a given size where soil fertility is spatially varied. A crop response function was used to simulate yield in relation to soil fertility. The farmer has a choice to manage variability using conventional, uniform fertilizer application methods, or variable rate technology. Three fertilizer inputs are used in the model -- N, P, and K. A 500-acre field was assumed. The field was divided into 2.5-acre grids. Soil fertility values were categorized as having low or high potential yields. Two adoption scenarios were considered: the producer purchases all the necessary technology, or the producer custom-hires services. In both scenarios, the producer was assumed to have a yield monitor equipped with GPS, mapping software (total, \$7855), to practice grid soil sampling (\$6.40/grid). In the first scenario, the producer purchased a variable rate applicator/controller for \$12,345. The custom application service costs the producer \$5/acre annually. The annualized fixed cost for the custom-hiring producer was \$5227, while the cost for the producer-owner was \$5665. Equipment life span was assumed to be 5 years with a discount rate of 5%. Service costs were assumed to decrease by 3% per annum. Nitrogen, potassium, and phosphorous were assumed to cost \$0.20, \$0.13, and \$0.24/lb, respectively.

Results/Conclusion: For all soil fertility zones considered in the simulation, site-specific management generated positive returns caused by yield increases. Returns from low-fertility zones ranged from \$3.20 to \$10.70/acre. High-fertility zones generated positive returns ranging from \$5.80 to \$23.70/acre. Fertilizer cost savings was also realized. On low-fertility areas, savings decreased from \$3.10 to \$1.30/acre. Fertility costs on high-quality zones decreased \$2.50/acre. The authors found that as soil fertility increased, fertilizer costs increased since the marginal productivity of fertilizer application is increased. The addition of extra fertilizer to high-fertility zones increased the yield, and was at least equal to the application costs. When net present value analysis of site-specific management strategies was considered, adoption was not profitable on low-quality soils and uniform soil distributions. Investment is stimulated when soil fertility variability increased. There were no differences between producer-owner and producer-custom hire scenarios, NPV, and the decision whether to adopt site-specific management. Immediate investment only makes sense when rent discount rate differentials are greater than the fixed costs of investment. Higher soil fertility values and greater variations in soil quality encourage adoption under uncertainty and depreciating asset scenarios. (RETURN TO INTRODUCTION.)

Crop: corn
Technology: VRT, simulation
Region: Midwest

Issaka, Mahaman. 1993. An evaluation of soil chemical properties variation in northern and southern Indiana. Ph.D. Thesis, Department of Agronomy, Purdue University, West Lafayette, IN. (Return to REFERENCES.)

Objective: To determine the economic feasibility of two variable rate fertilizer application technologies: the soil potential approach and the nutrient approach. The soil potential approach determines fertilization rates based on soil survey map units. It is assumed that different soil types have different yield potentials, and that by knowing the fertility of each soil type, appropriate fertilizer rates can be determined. The second approach is incorporates grid sampling in soil testing procedures. A map is created and fertilizer is applied according to the soil test results and estimated yield potential of each cell. Cells are assumed to be 2 to 3-acre plots.

Methods: Three management strategies were examined. Fertilizing by soil types (whole field), fertilizing by fertility zones based on kriging results and fertilizing according to cell values linked to grids. Grid cells were 900 m^2. Data was obtained from a research farm and a private farm where field N and P values were highly variable. Soil tests were conducted at both sites. At the both sites, soil-test results suggested three fertility zones. Four management zones were delineated based fertility variation. Recommended fertilizer rates as determined by the university extension service were adjusted according to soil test results. Three treatments were examined: whole field application, applications based on grid sampling, and management units determined by kriging. Each grid cells was fertilized to its optimum amount. Whole field application rates were based on soil sample averages. A partial budget was employed to evaluate the profitability of the three management strategies.

Results/Conclusion: Fertilizer use was reduced by kriging. Fertilizer use was lowest in grid sampling units. Yield for whole field management treatments was less (2894 bu) than grid-managed treatments (2963 bu). Treatments using kriged maps were intermediate. All variable rate treatments resulted in net return losses. The author assumes this was due to significant under-fertilization of some management units. The author emphasizes that these results are based on only one years' worth of data, and surmises that if looked at over a four-year period, cost analysis changes. Fertilizer use efficiency substantially increases using site-specific management strategies. In 1993, the high costs of testing were major constraints, and decreased the likelihood of realizing increased net returns. (Return to Table 9.)

Crop: corn

Technology: VRT, grid sampling
Region: Indiana

Kasowski, Mike, and Dave Genereux. 1994. Farming by the foot in the Red River valley. Agri Finance, December, p. 20. (Return to REFERENCES.)

Objective: To illustrate the advantages of soil testing using grid sampling methods in conjunction with variable rate fertilizer application. The authors are field technicians for a consulting firm that provides fertilizer recommendations to sugar beet farmers in Minnesota.

Methods: Testimonial based on personal experience is provided by the authors. Their advice to sugar beet farmers is that there is much to learn in terms of field variability vertically, not only horizontally. The authors provide rationale why it is equally important to test at 4-ft below field surface as it is to test at the commonly prescribed 2-ft depth.

Results/Conclusion: Fertilizer Recommendations based on test results from 4-ft below the field surfaces provided information that boosted profits and product quality. The authors revealed cases where profits have increased between $25 and $140/acre for some farmers when deeper soil samples were included in testing protocol. Some sample sites revealed ample amounts of available N. If recommendations had been based on samples taken at depth of 2-ft, these zones would have been over-fertilized. Revenue increases were tied to larger sugar beet yields, savings in fertilizer costs, and a higher-quality product. According to the technicians, an external benefit included less N being released into the environment. (Return to Table 9.)

Crop: sugar beets
Technology: grid sampling, VRT
Region: Minnesota

Kessler, Mark C., J. Lowenberg-DeBoer. 1998. Regression analysis of yield monitor data and its use in fine-tuning crop decisions. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 821-828, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The report investigates which how statistics can be used to assess site-specific responses to inputs, and how these relationships might augment revenue.

Methods: In this exploratory study, regression analysis was used to determine how SSM management influenced crop yield. Three years worth of production data (1994-1996) from an operating farm were used. Yield monitors quantified harvests. Whole field soil tests were carried out before 1994 on 0.5 -acre grids. Variables used in the historical regression model were yield, crop (corn or wheat), tillage, soil test year, soil pH, applied

N, P, and K, and planting date. The same variables used in the above model were included in the grid-based model, including production year, soil texture (sand, silt, or clay), cation-exchange capacity, and percent organic material. An economic analysis included corn price, as well as significant variables significant at the 0.05% level from the above models. These results were used to optimize input prices, output, and farm operation costs. Using coefficients generated from the first two models, three scenarios were simulated: a whole rate soil test an uniform application, using grid information to calculate optimum levels for each grid varying the fertilizer rate accordingly, and using grid information to determine whole field fertilizer rates.

Results/Conclusion: In the historical model, the most controllable variable seemed to be the planting date. There were no other variables under the control of management that were significant. The grid-based model explained some of the variation in the data. However, spatial correlation was not explained. Using assumed corn and fertilizer prices, whole field soil testing and uniform fertilizer application was the most economically feasible practice for this farm. The authors conclude that historical data does not provide much direction for management, and that grid based soil testing can generate useful coefficients for controlling certain management variable (such as fertilizer application rates). Additionally, the results presented are presumed to be affected by spatial correlation. Lastly, recommendations based on collected and analyzed information will be affected by market prices. (Return to Table 9.)

Crop: corn
Technology: VRT, modeling
Region: Indiana

Khanna, Madhu. 1999. Sequential adoption of site-specific technologies and its implications for nitrogen productivity: a double selectivity model. Selected paper for the annual meeting of the American Agricultural Economics Association, Nashville, TN, Aug 8-11, 1999. (Return to REFERENCES.)

Objective: To develop a model that explains the factors related to the adoption of site-specific crop management technologies, and the pattern and implications of adoption for nitrogen management. That an individual producer's decision to adopt any new agricultural technology most likely occurs sequentially is a central assumption of the model.

Methods: One thousand grain farmers in Indiana, Iowa, Illinois, and Wisconsin were randomly selected. Six hundred and fifty farmers responded to a survey which asked respondents why they chose one soil test over another, and whether or not this information was used for VRT. This study used eight main variables: scale economies, human capital, land ownership, soil quality, propensity to innovate, adoption costs, and location. A "double selectivity model" is used to differentiate farmers that do not adopt either soil testing technologies or VRT, soil testing only, or soil testing and VRT.

Results/Conclusion: The author found that one of the most influential factors of VRT adoption was location. Farmers in Indiana, Wisconsin, and Iowa were more likely to adopt soil testing technologies than farmers in Illinois. Proximity to farm and fertilizer dealerships influenced the adoption frequency of VRT. Acres farmed had no impact on the decision whether or not to adopt soil-testing technology. Producers farming higher quality soil were more likely to adopt VRT than those farming relatively poorer soil. However, gains in nitrogen productivity were greater on poorer soils following adoption of soil testing and VRT. Adoption of soil testing only did not affect nitrogen productivity. Farm owners were less likely to adopt VRT than those leasing land. Double selectivity model results suggest that corn productivity of farmers not adopting soil testing or VRT decreased as the acreage cropped increased. Farmers using manure produced more grain per unit nitrogen than farmers who did not. College educated non-adopters farming higher quality soils attained higher nitrogen productivity than other farmers. The author concludes that technically proficient, educated producers, capable of spreading the costs associate with learning and information gathering over a large number of acres were more likely to adopt soil testing and VRT. The model would be more realistic if yield data from crops (i.e. corn) was used in the analysis, and if the author incorporated more than one growing season in the analysis. A budget describing the costs "technological bundle" of VRT would reinforce the argument provided by the author that producers adopt technology sequentially. Instead, the report subsumes the components of VRT under the general heading of "soil testing" and "VRT."

Crop: cash grain crops
Technology: VRTN, modeling
Region: Illinois, Iowa, Indiana, Wisconsin

Khanna, Madhu, Onesime Faustin Epouche, and Robert Hornbaker. 1999. Site-specific crop management: adoption patterns and incentives. Review of Agricultural Economics 21(2): 455-472. (Return to REFERENCES.)

Objective: To investigate the extent to which producers are adopting precision agriculture technologies, identify an adoption pattern based on the components chosen by farmers, and possible trends associated with these choices. Site-specific technologies have been categorized into three general domains: (1) information collection and management technologies for discerning field variability; (2) technologies linking this information to the field, such as yield maps, combined with GPS or remote sensing; (3) application technologies allowing farmers to apply information, such as variable rate applicators.

Methods: One thousand mail surveys were sent to cash grain farmers in Iowa, Illinois, Indiana, and Wisconsin. Respondents were randomly chosen. They were asked whether they used computers, soil testing, grid sampling with GPS, application technologies, yield monitors, and variable rate application of pesticide, herbicides, or fertilizers.

Results/Conclusion: Adoption of simpler, diagnostic equipment such as computers and non-grid soil samples was more frequent than adoption of highly engineered technologies such as yield monitors, GPS and grid-based sampling. Individuals who had adopted use of the latter technologies owned or manage larger operations. The authors suggest that producers endowed with human capital, technical skills, and the resourcefulness required for collecting and analyzing highly detailed data were presumed to have lower costs of incorporating these technologies into their decision-making process. Adopters of advanced technologies were already using computers. Adopters tended to be less than 50-years old, had a college education, managed larger farms and had historically higher yields than non-adopters. The authors identified three adoption patterns: path dependency, leapfrog, and threshold adoption patterns. Survey results indicated that the first pattern represented the adoption behavior of most producers interviewed. Farmers had already incorporated computer technologies into their farming operations. A logical next-step would be a technology that would interface with this component. Adoption patterns for some farmers were of the second type. Producers would adopt advanced technology packages without having tested less complex precision agriculture technologies. According to the author, one factor impeding adoption rates is the lack of information about the benefits of precision agriculture. Another reason is that farmers are satisfied with their current production levels, their machinery, and their production routines. Payback from precision agriculture technologies is also dubious. The authors assume that as farm implements senesce, producers will be more willing to try technologies associated with precision agriculture.

Crop: na
Technology: precision agriculture, general
Region: Midwest

Kitchen, N.R., D.F. Hughes, K.A. Sudduth, and S.J. Birrell. 1994. Comparison of variable rate to single rate nitrogen fertilizer application: corn production and residual soil NO_3-N. Site-specific management for agricultural systems: proceedings from the 2nd international conference, March 27-30, Minneapolis, MN, p. 427-439. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The authors address the following questions: (1) Can NO_3 leaching be circumvented while increasing sustainable production of corn using VRT?; (2) how useful are yield maps from prior production years be for predicting next year's yield potential and corresponding fertilizer maps?

Methods: Four study sites over two growing seasons were subjected to conventional and VRT N application protocols. N application rates during the experiment were determined using yield maps generated from previous seasons' yield results. A combine equipped with sensors measured yield. N uptake by plants and unrecovered N were detected using soil samples. Grain production, unrecovered N, and post-harvest soil nitrates were measured. A crude partial budget was used to evaluate the profitability of VRT-N.

Results/Conclusion: Yield was not help nor hindered by VR. The authors found that N was more limiting a factor as VR applications reduced yield when all experimental units were compared across the first three study sites (claypan soils). Increased N limitation was accounted for by high soil moisture conditions during seed fill. When application strategies were compared across experimental units and treatment regimes, VR N produced better than expected yields. In study site 4 (alluvial soils), there were no differences between N application strategies. In the first three studies, unrecovered N decreased in the least productive soils when VR was used. Yield mapping improved the ability to apply N fertilizer accurately, in contrast to basing application decision on the "best years" or "best area." The authors provide a budget comparing conventional and VRT-N applications. In short, there was not much difference between expected returns of conventional and VR applications. The authors did not take into consideration the costs of conducting VR. Inclusion of this cost would probably render conventional application methods more cost effective than VR in this study.

Crop: corn
Technology: VRTN
Region: Missouri

Letey, J., H.J. Vaux, and E. Feinerman. 1984. Optimum crop water application as affected by uniformity of water infiltration. Agronomy Journal, 76 (May-June): 435-441.
(Return to REFERENCES.)

Objective: To report a methodology for determining how variable water infiltration rates on corn and cotton crops affects yield, optimum water application, and net returns.

Methods: A response function model is developed to determine the amount of irrigated water absorbed by crops, or lost to evapotransporation or run-off. Data was selected from other research results, as well as response functions for cotton and corn. Six arbitrary water infiltration rates were examined. Water infiltration rates correspond to amounts of water provided by irrigation.

Results/Conclusion: As infiltration rates variability increased, corn yield decreased. Applying prescribed amounts of water in these zones offset decreases in yield caused by infiltration non-uniformity. However, with cotton, additional water did not offset low yields when infiltration was non-uniform. When water prices were low and water infiltration rates were assumed to be heterogeneous, the optimal average amount of water increases. More water can be irrigated over a non-uniform field when water prices are low. The converse is true, as well. It can be inferred that by knowing field-water infiltration coefficients, hydrological maps could be developed to deliver prescribed amounts of water to specific infiltration management zones.
(Return to INTRODUCTION.)

Crop: corn, cotton
Technology: VRT-irrigation

Long, D.S., G.R. Carlson, and G.A. Nielsen. 1996. Cost analysis of variable rate application of nitrogen and phosphorus for wheat production in northern Montana. Precision agriculture: proceedings of the 3rd international conference, June 23-26, Minneapolis, MN, p.1019-1032. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To establish whether VRT is more profitable than conventional, uniform N-application strategies using yield goals and grid soil sampling of smaller field areas exhibiting spatial variations in productivity.

Methods: Three trials compared wheat production over three years. The first trial was conducted on a 41-ha field in a summer fallow rotation. The second site was a 21-ha field in a chemical fallow rotation. The third trial involved P fertilization on three 15-ha fields. Soil N was determined to establish treatment N rates. The experimental model was a randomized block design with three replications and five to six treatments. N rates were different each year treatments except for the increments (0 to 112, increasing by 23 kg/treatment) differentiating each treatment. P treatments were 0, 12, 24, 36, 48, and 60-kg P/ha. Fields were divided into strips and fertilizers applied accordingly. Experimental rates were determined using soil samples and remote sensing data that portioned fields into management-fertility zones. The number of samples conducted over the field and the grid sample sizes was not made explicit. However, soil test were conducted at two levels: 60 and 120-cm. Wheat was harvested using a yield monitor. Wheat prices yielded from both VRT and uniform rate treatments were determined using the average grain protein produced in each strip. Net returns for each treatment were calculated by subtracting fertilizer costs, soil-testing costs, and fertilizer application costs from gross returns. Nitrogen was assumed to be $0.407/kg. Soil sampling costs for a 41-ha field were assumed to be $55.00 per sample for uniform rate recommendations, and $48.00/sample for VRTN recommendations. Uniform rate application charges were $5.54/ha. VRTN application charges were $12.35/ha.

Results/Conclusions: First, the authors compare the returns from VRTN and uniform rate strategies in terms of fertilizer recommendations base on two different soil test depths. Profit-wise, returns from VRTN were superior than those from uniform rate technology at $433.00/ha at a cost of $43.00/ha and $372.00/ha at a cost of $17.00/ha, respectively, base on soil tests from the top 60-cm. Results were different when soil test data from the top 120-cm was used. Uniform rate treatments ($327.00/ha at a cost of $1.00/ha) were less cost effective than VRTN ($344.00/ha at a cost of $25.00/ha). The authors attribute this to the skewed results generated by the soil tests. A few regions in the field had very high nitrogen readings. Using averages, other portions of the field with lower N rates would not receive sufficient amount of N fertilizer under a uniform application strategy. Results of profitability analyses comparing VRTN and uniform rates were similar when data from the following growing season were analyzed. Returns from VRTN were greater than they were for uniform rate treatments. However, results were attributed to nitrogen carry-over effects rather than skewed results. More N could be precisely applied to region known to be high-yielding using VRTN. Returns were not compared for P trials. Using market quotes for protein content proved useful during profitability analyses. This method links farm activities to wider, off-farm contexts, and demonstrate the connectivity of on-farm management decisions and less controllable, external processes such as markets and costs of implementing new technologies.

Crop: wheat
Technology: VRTN
Region: Montana

Lilleboe, D. 1996. Will it pay? The Sugar beet Grower, February, p. 18-20. (Return to REFERENCES.)

Objective: To describe the use of grid soil sampling and variable rate fertilizer application in the sugar beet industry in South Dakota and Minnesota. Specific attention is paid to the profitability of the practices combined, and the total acreage of sugar beet farms that have adopted these technologies.

Methods: The author uses case studies, farmer testimonials, and regional production data to describe the grid sampling/variable rate application process, and the net returns resulting from these precision agriculture technologies.

Results/Conclusion: Responses from a consultant working for a sugar beet processing company point out that variable rate fertilizer application will only be profitable on some sugar beet fields. If grid-sampling results indicate that field fertility is not highly variable, then VRT should not be considered. To little nitrogen results in poor yields, while too much results in low-quality sugar beets. Grid sampling can indicate where exactly low- and high-fertility zones are located in fields, and at what ratio. Where soil nitrogen content was less than 30 lbs/acre, returns from grid-sampling/VRT paid off only 31% of the time. The consultant said that 70% of the 897 fields sampled had enough soil fertility variability for them to be considered candidates for variable rate fertilizer spreading. In this consultants work zone, 80% of his recommendations were successful in terms of profitability. Other zones in Minn-Dak fared less well at 50% of the recommendations making returns on grid-sampling/VRT investments. Variations in weather patterns were held responsible for these results. The author indicates that the general attitude held by companies providing grid-sampling/VRT services is that the more information a producers can have about their field, the easier it is to pin-point problem area. When these areas are found, then more or less dollars and cents can be spent there.

Crop: sugar beets
Technology: grid sampling, VRT
Region: South Dakota, Minnesota

Linsley, C.M., and F.C. Bauer. 1929. Test your soil for acidity. Circular 346, University of Illinois, Agriculture Experiment Station. (Return to REFERENCES.)

Objective: An early extension circulation promotes systematic testing of soil pH, and using the results to make pH-distribution maps representing management zones.

Methods: A step-by-step methodology how to test soil pH, then use the information to create maps is given. A spacing of 8 rods (132 ft) between sampling points is recommended. A simple net return minus costs was used to estimate savings gained using this information strategy.

Results/Conclusion: A case study is offered by the authors to emphasize the importance of testing soil before purchasing lime. In 1929, not testing soil pH cost farmers "many thousands of dollars" each year in both lime and clover seed. Farmers would sow at least 40-acres of red or sweet clover on land that was too acidic. Clover will not grow on acidic soils. Unaware of the soil pH of a field, a farmer would plant clover on acidic fields and "lose $50 to $100 dollars" worth of seed for every 40-acres seeded. The onus of low clover production was commonly attributed to poor weather. The authors argue that if this amount were invested in agricultural lime, low-pH fields would be ameliorated. They warn, however that the spatial variability of field pH has to be determined before purchasing lime. In another testimonial, a farmer had ordered 120 tons of limestone for a 40-acre field. Before the shipment arrived, he had conducted a soil test, and mapped the results. The results indicated that he needed to apply only 60 tons of lime, and would have saved $120. The authors end the circular: "*Don't Guess--Test*."

Crop: clover
Technology: VRT
Region: Illinois

Lowenberg-DeBoer, J., R. Nielsen, and S. Hawkins. 1994. Management of intrafield variability in large-scale agriculture: a farming systems perspective. Systems-Oriented Research in Agriculture and Rural development: International Symposium, Montpellier, Francs, November 21-25, 1994, p. 551-555. (Return to REFERENCES.)

Objective: To determine the best methods to use information-generating tools such as GPS, on-board computers, variable fertilizer applicators, and on-the-go yield monitors in variable rate fertilization programs. The economic importance of understanding intrafield variability is emphasized, along with VRT efficacy based on decisions made using soil fertility maps.

Methods: Fields on four farms were divided into three equal-sized plots. Three fertilization treatments were tested: whole field, soil type, and grid management. Whole field fertilizer rates were based on the average nutrient levels (P and K) of two soil samples per field. Fertilizer rates for the second treatment were based on soil test results for the specific soil type. A uniform fertilizer rate was applied to the soil type based on recommendations according to the test results. The third treatment divided the field in a series of grids. Soil samples were taken from 1.4-ha cells within each grid. A recommended fertilizer rate is made for each cell. Fertilizer is applied uniformly in each cell. A GPS-quipped yield monitor was used to quantify production and log yield spatial distribution. The relative costs of three soil mapping techniques were compared. These techniques were grid-based maps, kriged maps based on linear semivariograms, and kriged maps using a Gaussian model.

Results/Conclusion: VRT fertilizer recommendations are sensitive to the mapping technique used to determine soil fertility zones. However, the researchers found that kriged maps revealed soil fertility patterns that were incongruent to the farmers' experience with the field. Furthermore, kriged maps did not necessarily correspond with soil test results. Grid-based maps cost $24.83/ha, while the kriged maps cost $18.43 and $15.45/ha, respectively. In this report, soil test cost between $6 and $18/sample, depending on the type of test. When spread out over a three to four year period (as dealerships providing these services will do), grid soil tests fall to $2.50/ha annually. Mapping fees under this system are $7/ha. Since variable rate spreaders can cost on the order of $250,000, farmers are more likely to hire VRA services. Conventional custom spreading costs $10/ha, while VRT spreading costs are higher at $13 to $18/ha. The authors conclude that framers' perceive VRA as a method to increase efficiency on a given field, rather than a way to expand farm operations. Agrochemical dealerships see VRA as a way to assuage criticism from the environmental sector, to market a new product, and as a new profit-generating mechanism. The producer, according to the authors, will become either coordinators of this new technology, or at worst, laborers implementing outside experts' management plans. (RETURN TO INTRODUCTION.)

Crop: corn
Technology: VRT
Region: Indiana

Lowenberg-Deboer, Jess. 1995. Economics of precision farming: payoff in the future. Paper presented at the Precisions Decisions Conference, Champaign, Illinois, November 27-28, 1995. (Return to REFERENCES.)

Objective: To provide a general review of the economics of PA, identify possible future benefits, and define an adoption strategy for "long term competitive advantage."

Methods: The author defines terms such as cost, benefits, short-term profitability, and adoption strategies in relation to PA.

Results/Conclusion:

Table 21. Profitability conclusions from 11 Precision Framing Studies

Study	Crop	Inputs Managed	Treatment of Sampling & VRT Cost ($)	PA Profitability
Carr et al.	Wheat, barley	N, P, K	Not included	Mixed
Fiez et al.	Wheat	N	Not included	Yes, potentially
Hammond	Potato	P, K	Variable & fixed	Inconclusive (costs only)
Lowenberg-DeBoer et al.	Corn	P, K	Variable & fixed, custom rates	No, but might for low-soil test fields
Wibawa et al.	Wheat	N, P	Variable & fixed w/1-yr. amort.	No (but over-est. annual fixed costs)
Wollenhaupt and Buchholz	Corn	P, K	Variable & fixed w/4-yr. amort.	Mixed; deps. on yield gain
Wollenhaupt and Wolkowski	Corn	P, K	Variable & fixed w/4-yr. amort.	Mixed; deps. on sampling density and amort. period
Simulated Yields				
Beuerlein & Schmidt	Corn, soy	P, K	Variable & sample; no equip.	No, but more efficient fertilizer use
Hayes et al.	Corn	N	Not included	Higher revenue has potential to cover costs
Hertz and Hibbard	Corn	P, K	Variable & fixed, custom rates	No, but close to uniform in proftiabiulity
Mahaman	Corn	P, K	Variable & fixed, custom rates	No if 1-yr sample amort.; yes if 4-yr sample amort.

Source: Lowenberg-DeBoer, J., and S.M. Swinton. 1997.

Precision agriculture economic feasibility studies have oftentimes omitted the costs of developing human capital in budgets. Human capital development would include training individuals how to use, interpret, and maintain PA-related equipment, including computer training and data interpretation. Similarly, the time spent while learning these new technologies, and the costs associated with lost time have not been included in budget analyses. Human development costs also include any workshops or seminars that address training issues. Useful life of equipment should be incorporated into profitability analysis. If equipment has to be updated or replaced after four years, these costs could substantially affect partial budget analyses. Generally, returns from PA technologies are higher and more consistent when used with high value crops. Returns from PA to production of bulk commodities are low. However, these figures might be confounded by management strategies. The author concludes that agriculture has become a data driven, knowledge-based enterprise. Some producers will opt for custom PA services in efforts to build personal data bases reflecting the spatial variability of their farms. Other producers' first venture into PA might include purchase of a yield monitor, as has been the case with many grain farmers on the heartland. Yield monitors set the stage for adoption of GPS guidance systems, yield mapping and management decisions based on the combination of these technologies. Over time some PA technologies will become standard practices in North America. Other technologies, or combinations of technology will become obsolete.

Crop: any
Technology: PA summary
Region: North America

Lowenberg-DeBoer, J. 1995. Management of precision agricultural data. Selected paper presented at the Annual Meeting of the American Agricultural Economics Association, Indianapolis, August 1995. (Return to REFERENCES.)

Objective: To detail the problems of managing massive amounts of data generated by precision agriculture technologies. The analysis entertains information ownership, information use, and costs of managing information.

Methods: Using personal experience and recent literature, the author reviews the current state of information collection, management, and associated costs for precision agriculture technologies.

Results/Conclusion: The author concludes that an effective method for understanding the costs associated with managing precision agriculture data is focusing on the economics of scale associated with information costs, management, and collection. That farming enterprises capable of affording the composite of technologies needed to effectively implement most precision agriculture technologies, and that concomitantly large amounts of information will be needed to provide these technologies effective leads to the formation of professional private or academic organizations specialized in this task. (RETURN TO INTRODUCTION.)

Crop: na
Technology: Precision agriculture, information management
Region: all

Lowenberg-Deboer, Jess, Steve Hawkins, and Robert Nielson. 1994. Economics of precision farming. Extension Manual, Department of Agricultural Economics, Purdue University, West Lafayette, IN 47907. (Return to REFERENCES.)

Objective: To summarize research results investigating the management of precision farming technology.

Methods: In 1993, variable rate application trials using P and K were conducted on four fields (eight producers, total), each approximately 50-acres. Soil variability, mapping techniques, and the efficacy of on-the-go yield monitor data, was investigated.

Results/Conclusion: Soil test results indicated that well managed fields display large differences in soil fertility even after being managed on a whole-field basis. Variation stems from varying soil types, as well as past management decisions. Magnitude of variability was different for each farm meaning variable results from one farm may not have indicated P or K applications, whereas the range of variability on another farm warranted site-specific application of these elements. Three figures display 3-dimnensional grid maps of P spatial variability. Each map was generated using different inferential techniques: grid mapping (based on 3-acre grids), and krigging using Gaussian or linear models. The grid map and custom P application cost 60% more than kriged maps using the Gaussian model. The kriged map using the linear model, including P application cost 80% that of the grid map. Gird maps generate a wider range of extreme high and low fertility values than kriged maps. Yield monitor results proved to be within 2% of weigh wagon yield measurements. Where farms are well-managed, the authors conclude that returns from PA will be realized not in increased yields, but in decreased input use. The authors warn that producers considering adopting PA technologies have to keep in mind human capital costs, computer software and hardware costs, and the costs associated with learning and training.

Table 22. An example of precision farming costs for a 3-acre grid and a 4-year soil sampling cycle.

Item	Unit	Quantity	Price	Amount
Soil sampling	sample	1/3*1/4	9.00	0.75
Map making	acre	1	2.50	2.50
Record keeping	acre	1	1.00	1.00
Extra application cost	acre	1	3.00	3.00
Total cost, $/a				7.25

(Return to Table Listing)

Crop: corn
Technology: mapping, soil testing, yield monitoring
Region: Indiana

Lowenberg-DeBoer, Jess. 1996. Precision farming and the new information technology: implications for farm management, policy, and research: discussion. American Journal of Agricultural Economics, 78: 1281-1284. (Return to REFERENCES.)

Objective: To focus on the historical development, the state of economic research in the precision agriculture field.

Methods: The author reviews and critiques three reports concerning precision agriculture. Of import is the lack of attention paid to the historical development of precision agriculture, the value of economic analysis and its role in determining the feasibility of precision agriculture, and the needs created by the inception of precision agriculture, such as decision support systems and data analysis and management.

Results/Conclusion: The development of precision agriculture in the United States can be compared to the adoption of mechanized farm implements. Like the incorporation of the tractor into farm operations, an extensive history of informal and formal crop systems information where producers balance costs and benefits of data collection, analysis, and implementation are the foundation of precision agriculture, and influence the rate and frequency of adoption on a farm-by-farm basis. Additionally, assuming widespread adoption of precision agriculture, no one can predict the consequences that will follow. With the complete adoption of motorized implements, not only the structure of the farm changed, but also farming as a lifestyle was transformed into a business. These whole-farm changes were not anticipated with the inception of motorized farm implements. Economically, there has been little research how precision agriculture technologies have affected farming operations at the whole-farm level, or the agricultural sector as a whole. Structural changes might include the breadth of control over more acreage, precision agriculture product diversification, and food safety. The promotion of precision agriculture has created a need for human resources. Experts understanding risk profit potential, structural impact, and policy implications become essential as precision agriculture components are integrated into farming systems. The author anticipates the formation of interdisciplinary teams that will focus on data management and interpretation, development of algorithms for determining crop yield responses, and education and training. These decision support system teams might include nation-wide farm implement dealerships, private consulting services, and university departments. (RETURN TO INTRODUCTION.)

Crop: any
Technology: precision agriculture, general
Region: United States

Lowenberg-DeBoer, J., and M. Boehlje. 1996. Revolution, evolution, or dead-end: economic perspectives on precision agriculture. Proceedings of the 3rd international conference, June 23-26, Minneapolis, MN, p. 923-944. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The objective of this report is to provide an economic perspective on precision agriculture. Three main themes are presented. First, the profitable margin of precision agriculture at the farm level is discussed. Then, the authors discuss the economics of information collection and management. Lastly, how precision agriculture might further industrialize North American agriculture is discussed.

Methods: The authors review studies that examine profitability of precision farming. First, they present a brief epistemology of knowledge production followed by the forms of knowledge that comprise useful information for precision agriculture. Then, farm level profitability studies and equations used to understand farm level profitability are given. Data from a survey conducted by the authors is presented. Respondents were farmers who had practiced precision agriculture in one form or another at one time. They were asked where they had obtained information about precision agriculture, and which sources were most valuable. Partial budget methods are outlined, followed by a critique of several partial budget studies.

Results/Conclusion: The authors characterize information useful to the objectives of precision agriculture as timely, accurate, objective, complete, clear, and convenient. Reviewing partial budgets, the authors suggest that results from previous studies were contingent upon the manner in which the costs of sampling and variable rate application were handled. When the authors asked why some partial budget assessments of SSM were profitable, they found that the costs associated with information collection and management were excluded. Similarly, the question was asked why some partial budget analyses found SSM unprofitable. Simply, the costs outweighed the benefits. But information collection and management costs were not spread out over the entire production spectrum. Instead, they were only distributed over a few nutrients. High soil fertility implies low costs for fertilizers; hence, benefits are not attributable to SSM from this perspective. That fixed costs were not annualized and inflation of fixed costs due to small grid cells used for soil sampling are other reasons why SSM may have been classified as unprofitable in these partial budget studies. For mixed results, SSM profitability hinged upon attainable yield, sampling density, and the duration of the validity of soil maps. Information collection and management costs should be distributed over many inputs, not just fertilizer, since information is a resource that can be combined with other knowledge bases or used alone to attack other farm functions besides fertilization activities. According to the authors, precision agriculture could potentially change the present structure of industrial agriculture by reducing production costs while increasing efficiency, expanding control over previously uncontrollable variables, diversifying products, safer foods, and environmental benefits. (RETURN TO INTRODUCTION.)

Crop: any
Technology: precision agriculture
Region: North America/any

Lowenberg-DeBoer, J. 1997. Taking a broader view of precision farming benefits. Modern Agriculture, 1(2): 32-33, April/May 1997. (Return to REFERENCES.)

Objective: To examine the economics of in precision agriculture other than yield increases and input reduction. These two field-level factors are commonly used to gauge the economic feasibility of precision agriculture technologies. A broader definition provides a more accurate and realistic assessment of the value of precision agriculture.

Methods: The author uses personal experience to discuss potential benefits of precision agriculture other than increased yield and input reduction. A brief list of economic terms is presented, along with their definitions, and how they relate to precision agriculture.

Results/Conclusion: Other potential benefits of precision agriculture include diagnostic information, efficient equipment use, risk reduction, monitoring and supervision, product diversification, food safety, and environmental stewardship. Diagnostic information includes yield maps, soil maps, or other maps representing crop-field spatial and temporal relations. When diagnostic information is collected over time, it can be used in whole-field management strategies and long-term planning. Efficient use of equipment is another potential benefit of precision agriculture. With refined and detailed information about weather patterns or field conditions, operators can better schedule fertilizer application dates and sequencing use of farm machinery. GPS technologies enable operators to maneuver at night or during poor weather conditions. Overlaps and skips are also reduced with GPS technology. Risks can be reduced with adoption of precision agriculture technology. At the field level, site-specific management practices can reduce intrafield variability, which results in a decrease of variability in net returns across the entire field. At the whole-farm level information generated by precision agriculture can be used to make informed decisions about crop rotation sequences, marketing strategies, and crop variety. Information from GPS units can facilitate monitoring and supervision of farm employees and machine operators. Activities such as spraying or planting can be logged then evaluated at a later time. Monitoring crop growth during the growing season is a labor-intensive endeavor. GPS technology decreases the amount of time spent scouting fields for problem areas. Precision agriculture may aid producers in diversifying their products. For example, exploiting the natural topography of a field could enhance wheat protein content. Knowledge of this information could provide a producer more than one-grain grade at harvest. Food safety can also be enhanced with precision agriculture technologies. Field operation can be recorded, so that if problems arise, the exact origin of the problem can be located in the field, correlated with a fertilization record, and matched to a fertilizer map if necessary. By limiting fertilizer input based on knowledge about soil fertility zones, precision agriculture can also reduce the risk of groundwater contamination. (RETURN TO INTRODUCTION.)

Crop: any
Technology: precision agriculture, general
Region: any

Lowenberg-DeBoer, J. 1997. Bumpy road to adoption of precision agriculture. Purdue Agricultural Economics Report, November 1997, p. 1-4. (Return to REFERENCES.)

Objective: To identify patterns characteristic of technological change with the intent to provide producers and others involved in agribusiness a historical perspective that may be useful for making decisions about adopting precision agriculture technology.

Methods: The historical development and fate of several agricultural innovations is reviewed. Particular emphasis is placed on hybridization and farm implement mechanization.

Results/Conclusion: If a graph were used to indicate the adoption of a particular technology, an S-shaped curve would emerge. At first, there is only a slight rise from the inception of the technology and the number of users. Combinations of factors contributing to this might include the region specificity of the product, marketing problems, cost, a general unwillingness of the target group to change current practices, or a combination of these. Assuming the technology produces any economic benefit, a group of early adopters, or innovators, will continue to use and perhaps modify said technology. The curve exponentially rises as contemporaries too implement and adopt the technological package after seeing the benefits gained by their neighbors. The s-curve plateaus after the spread of the technology has saturated the user-group community. Either some refuse to adopt the product, or the returns diminish as higher revenues generated by the technology become stabilized. The problem faced by precision agriculture is that it is not a complete, unified package. Precision agriculture is currently more of a concept than a product. Whereas tractors and hybrid corn essentially arrived as one package deal, precision agriculture is comprised of several kinds of technology, including variable rate spreaders and applicators, GPS and GIS services, yield monitors, soil fertility and conductivity maps, data analysis and management, and computer hardware and software. The author concludes that the adoption pattern of precision agriculture will not follow the traditional s-shaped curve for several reasons. The technologies that make up precision agriculture are immature, and are still in the research and development phase. This stage lends itself to experimentation and tinkering by user-groups. Producers will pick and choose which components suit their operations, and discard others that do not. Secondly, precision agriculture is, by definition, information technology applied to agriculture. There is currently no consistently reliable institution to handle the vast amounts of information assumed to be required that make precision agriculture work. Lastly, the agricultural sector has become a riskier business since the government has withdrawn from price stabilization programs. Although nearly 13% of today's combines are outfitted with yield monitors, these factors challenge rapid adoption of precision agriculture, especially in the corn-belt region.

Crop: any, mainly corn
Technology: precision agriculture, technology adoption
Region: any, mainly Midwest

Lowenberg-Deboer, Jess. 1997. Economics of precision farming: implications for the Canadian prairies. *In* Farming to the Future, Precision Agriculture Conference, Brandon, Manitoba, November 1997. (Return to REFERENCES.)

Objective: To provide information pertaining to adoption strategies of PA-related technologies in Canadian prairie-lands. The author reviews the current state of the economics of PA, highlight key issues relating to the adoption of VRT, discuss other possible uses of PA-related technology that may play promote profitability, and review adoption patterns.

Methods: The author offers personal experience and knowledge while describing how the costs and benefits associated with PA adoption are affected by short term profitability, information, equipment efficiency, risk reduction, and product differentiation.

Results/Conclusion: PA agriculture feasibility studies focus on changes in crop input costs (such as fertilizer and herbicide), but have sometimes ignored investment costs, especially costs associated with human capital (training personal, learning curves, database management and other computer skills). Furthermore, not annualizing the useful lifetime of equipment into budget analyses ignores annual cost fees or equipment, thus potentially underestimating PA profitability. For example, computers or software may be obsolete within five years. Omitting equipment deprecation, the annual use costs can be relatively high. The author suggest that the benefits of PA have been difficult to measure or generalize since there is still debate amongst researchers as to which appropriate experimental designs are useful for validating yield monitor data, and which models best reflect field variability are still under development. The central factors governing VRT profitability and adoption are: (1) whether "an integrated system with site-specific management multiple inputs" exist or is available to a producer (2) the development of better crop response function models, (3) PA-related equipment availability on a mass-level, (4) accumulated experience of producers using a composite of PA technologies. Diagnostic information generated by yield monitors, remote sensing, and grid soil sampling not only identifies spatial variability patterns in fields. Diagnostic information as records becomes a whole farm information system. Pa technologies can improve equipment efficiency. For example, GPS guidance packages enable operators to work fields at night, and information about soil fertility and weather patterns could be used schedule and sequence equipment use. Crop risk can be reduced using PA technologies as well. For example, VRT P & K applications combined with grid soil tests have been shown to reduce net return variability by 25%. Lastly, on-the-go yield monitors could potentially help differentiate crops into two or more quality grades. The author concludes by describing the adoption patterns characterizing PA technology (see Lowenberg-DeBoer, J. 1998.).

Crop: na
Technology: PA, general adoption
Region: Canada

Lowenberg-DeBoer, J., and S.M Swinton. 1997. Economics of site-specific management in agricultural crops. *In* Site-specific management for agricultural systems, p. 369-396, ASA/CSSA/SSSA/, Madison, WI. (Return to REFERENCES.)

Objective: The authors focus on the variables needed to verify site-specific management (SSM) profitability. In additional, field level economic studies are reviewed to understand necessary conditions for SSM adoption in terms of risk, profitability, and environmental regulations. Lastly, the authors asked how SSM would impact U.S. agriculture.

Methods: The study provides a protocol for the economic analysis of SSM. In addition, it provides a review of the available literature on this topic. The authors provide a vocabulary for understanding SSM in economic terms. Techniques such as partial budgeting, investment analysis, calculations for gross margin and net revenue, and methods to factor in environmental benefits are included, along with a literature review of SSM material.

Results/Conclusion: SSM can provide a "spatial dimension" to crop management. The large amounts of information needed to understand spatial dynamics can be facilitated using automated data gathering techniques. However, research on the economic feasibility of SSM has not included costs associated with learning, training, or information collection and management. Other studies have neglected the use of actual field data in their estimations. A flowchart provides a systematic examination whether or not SSM will be profitable for a farm firm. First, partial budget reflecting cash flow change of a typical production season needs to be enumerated. If SSM does not cover variable operating costs, then the farm manager will most likely not adopt it. If these costs are covered, the next step in the decision making process is to conduct an investment analysis. Added variable costs of SSM include, for example, precision spreading costs, map making, soil testing, and training. When additional variable costs of SSM are covered, then an investment analysis estimating the capital costs of information collection and management, and special equipment needed for SSM is made. Some investments can be annualized since they are useful for several years. Examples include computer software and hardware, field sampling, data input and analysis, and data base development. Adoption risks can be factored into the decision making process. Yield variance from SSM-managed fields can be compared with historical yields of the same (or similar) fields that have been managed under conventional practices (i.e. uniform fertilizer application). A risk difficult to quantify is that of durable goods, discontinuation of their production, and cessation of support services. This typical pattern observed with the introduction of new technologies characterizes SSM adoption as well. Software or hardware may prove to be useless. Lastly, even if partial budgeting and investment analyses demonstrate that SSM may not be cost effective, environmental benefits are a form of direct financial gain or contribute to wider social well being and can be factored into the decision making process. SSM profitability is site-specific. SSM implementation should be determined on a farm-by-farm /field-by-field basis. Difficulties evaluating the economic benefits of SSM include connecting changes in crop yield to SSM. Long-term field studies understood using time series, auto-, and spatial correlation analysis are techniques capable of explaining the cause and effect mechanisms between crop yield and SSM. These question remains: how much detail is needed to manage fields using SSM technology?

Table 23. Gross margin and net revenue calculation example for variable rate technology application of P and K plus yield monitoring.

Item	Unit	Quantity	Unit Price	Total
Change in crop revenue corn yield change	Kg(bu)	11,441 (450)	$0.09 ($2.30)	$1035.00
Soybean yield change	Kg(bu)	1,362 (50)	$0.195 ($5.30)	$265.00
Change in variable cost				
SSM* services	Ha(acre)	40.5(100)	$17.91($7.25)	-$725.00
Change in fertilizer cost	Ha(acre)	40.5(100)	$7.93($3.21)	-$321.00
Differential correction fee	yr	1	$600	-$80.00
Added repair cost	Ha(acre)	40.5(100)	$0.32($0.13)	-$13.15
Added interest on variable costs at 10% for 6 mos	dollars	$1139	5.00%	-%56.96
Change in total gross margin	Ha(acre)	1		$1.04
Capital costs				
Yield monitor	Ha(acre)	40.5(100)	$5.41($2.19)	-$219.26
GPS unit	Ha(acre)	40.5(100)	$2.45($0.99)	-$98.67
Training	Ha(acre)	40.5(100)	$0.67($0.27)	-$26.81
Change in total net revenue	Ha(acre)	40.5(100)		-$240.84
Change in net revenue per ha^{-1} ($acre^{-1}$) unit land	ha^{-1} ($acre^{-1}$)	1		-$5.95(-$2.41)

(Return to Table 9, Table Listing, or INTRODUCTION.)

Crop: corn, soybean, any
Technology: VRT, site-specific management
Region: any

Lowenberg-DeBoer, J. 1998. Economics of variable rate planting by yield potential zones. Purdue Agricultural Economics Report, May 1998, p. 6-7. (Return to REFERENCES.)

Objective: To examine the profitability of variable rate seeding of corn using information about crop yield in relation to planting density, crop response functions by yield potential.

Methods: A spreadsheet model was developed to determine the profitability of varying seeding rates for corn. Data from Pioneer Hi-Bred agronomic reports was used to estimate corn yields. Yield potential zones varied corn yield response in the model. It was assumed that yield potential zones varied spatially, and that these zones were mapped. High, medium, and low yielding zones of were considered 180, 120-140, and less than 100 bu/acre, respectively. Three seeding rates were compared. A uniform seeding rate achieved a plant population of 28,000/acre. This treatment was the control. Treatments compared with the uniform seeding rate were variable rate-agronomic rule, and variable rate-economic rule. The former rate was based on Pioneer recommendations. Seeding rate recommendations for low-, medium-, and high-yielding zones were 18,000, 28,000, and 30,000, respectively. The variable rate-economic was based on the economic criteria of marginal returns. The marginal value of the additional product must be equal to the marginal cost of the extra input in each management zone. Seeding rates for this scenario were 20,000, 26,000, and 30,000 per acre for low-, medium- and high-yielding zones, respectively. Price assumptions included corn at harvest ($3/bu), seed ($67/bag), dryer fuel ($0.50/gal), variable rate controller and monitor ($9500, with a 5-year life span), and interest rate (10%). A 1000-acre field planted with corn was assumed as well. Only seeding rate was site-specific. Only two yield zones were considered at one time for simplicity. Additional scenarios included varying seed prices and variable rate equipment costs. Initial simulations considered variable rate technology as the only investment. Additional sensitivity analyses included costs of GPS services and additional computer hardware and software.

Results/Conclusion: Results indicated that farms with some low-yielding land (<100 bu/acre) economically benefited from variable rate planting. However, these benefits vary depending on the low-, medium-, and high-yielding land ratio. Both variable rate planting strategies showed modest 10% returns on low-yielding land. Results of the baseline scenario produced the largest returns at $4/acre when the low:high-yielding land ratio was 1:9 for both VRT seeding strategies. Seed costs savings between $50 and $110 were realized when the ratio of low- to high-yielding land was larger. Uniform rate planting was economical for fields with medium- and high-yield land mixes since variable rate seeding strategies resulted in net losses during trial runs.

Table 24. Reported returns from variable rate seeding strategies

	VRT-agronomic recommendation	VRT-economic decision rule
Percentage of field low- or medium-yielding	------------------------------$/acre/yr------------------------------	
Low yield potential land		
10%	0.47	0.50
50%	2.16	2.32
90%	3.85	4.15
Medium yield potential		
10%	-0.05	0.00
50%	-0.44	-0.22
90%	-0.83	-0.43

(Return to Table Listing.)

Crop: corn

Technology: VRT-planting
Region: Midwest

Lowenberg-DeBoer, J. 1998. Precision agriculture in Argentina. Earth Observation Magazine, Spring, p. MA13-MA15. (Return to REFERENCES.)

Objective: To describe the adoption process of precision agriculture in Argentina. Constraints facing Argentinean producers are discussed, such the piecemeal incorporation of precision agriculture components, and different government support structures influencing agriculture in Argentina.

Methods: Personal observation, interviews with Argentinean producers, and survey of production data from research stations are summarized to provide a picture of the state of precision agriculture in Argentina.

Results/Conclusion: At least four differences distinguish adoption of precision agriculture in Argentina from the United States: there are higher investment costs, more risk, less management-induced soil variability, and the propensity to higher custom operators. Because higher interest rates, obstacles obtaining credit, and higher technology costs and risks dissuade investment Argentina. The author estimates that producers will adopt precision agriculture components such as yield monitors and other information-generating devices more readily than variable rate applicators, since the devices can be retrofitted to extant machinery, and can be used for multiple purposes. Adoption of technologies useful for mapping seems ideal since management decisions are made from an off-farm, and not directly by those working on the tractor. Approximately 1-2% of the combines in Argentina are equipped with yield monitors, compared to 4% in the United States. Spraying guidance systems using GPS are spreading rapidly, but variable rate spreaders are not. As more acres are farmed, the costs of GPS units and yield monitors will decrease since per acre costs are lowered. Apart from socioeconomic structures, training operators how to use these new technologies, data interpretation, adapting variable rate technologies to the Argentinean landscape, and developing a local data pool challenge development of precision agriculture in Argentina.

Crop: na
Technology: precision agriculture
Region: Argentina

Lowenberg-DeBoer, J. 1998. Adoption patterns for precision agriculture. Agricultural Machine Systems, SP-1383, Society for Automotive Engineers, Warrendale, PA, September 1998. (Return to REFERENCES.)

Objective: To describe the adoption process of agricultural technology. Attention is paid to the history of hybrid seed and tractors in the United States. Constraints impeding adoption of precision agriculture are outlined.

Methods: Historical references are cited. A primer on technology adoption theory is provided, then adoption patterns of precision agriculture are fitted to the familiar "**S**" curve. Where precision agriculture is located on this curve, and why is explored. Future directions are forecasted.

Results/Conclusion: Precision agriculture is not a new concept. The technologies that define it in the context of modern, capital intensive industrial agriculture are. Producers are faced with a menagerie of technologies such as GPS, GIS, yield monitors, variable rate applicators, grid soil testing, and computer hardware and software needed to process and manage the voluminous amounts of data potentially available using these technologies. The current state of acceptance of precision agriculture is analogous the adoption of the tractor, and its evolution from steam to fuel-powered, and stepwise acceptance by agricultural regions. What sets precision agriculture apart from other technologies that revolutionized agriculture is that precision agriculture is a composite of technologies, not one package. The technology is still new, and producers purchase one or two components, then modify them according to their own management styles. That precision agriculture is information technology applied to agriculture implies data acquisition and management. New forms of data and large amounts of it are now readily available. But storage and acquisition of this information is a new cost not usually anticipated by producers wishing to incorporate precision agriculture into their operations. Information ownership is also an issue. Though producers might pay for grid sampling or mapping services, they may not be capable of storing the data. Institutions or private organizations are presently bettered equipped to handle these kinds of data structures. Furthermore, pooled data could be beneficial at regional levels. Information could be used to confirm environmental problems and solutions with externalities related chemical output or effluent. Risks not directly related to precision agriculture hinder its adoption. Agriculture is an increasingly risky enterprise in itself with reduced government price stabilization. Factors influencing technology adoption patterns are age, education, risk preference, adjustment costs, learning costs how to use the technology and acceptance of the technology by contemporaries.

Crop: na
Technology: precision agriculture
Region: Midwest U.S.

Lowenberg-DeBoer, J. 1998. Economics of variable rate planting for corn. Precision agriculture: proceedings of the 4th international conference, July 19-22, St. Paul, MN, p. 1643-1651. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To investigate the profitability of variable rate seeding of corn information about crop response to plant populations. (Return to Table 9.)

Crop: corn
Technology: VRT
Region: Indiana

Lowenberg-DeBoer, J. 1998. What price is right? Farm Chemicals, 161(4): 20-23. (Return to REFERENCES.)

Objective: To clarify the why custom fees for precision agriculture services varies across the Midwest.

Methods: The author reviews price variations across the Midwest for precision agriculture services. Prices are quoted from producers who have bought products, or from dealerships.

Results/Conclusion: Grid sampling fees vary depending on the size of the grid, the number and types of soil tests taken, the sampling density and if field mapping is recommended. The type of equipment used, additional components attached to the sale package, whether map making is recommended, and whether the fee is applied to the entire field or just where prescriptions are applied determine variable rate application fees. (Return to Table 9.)

Table 25. Costs/acre of various services offered by dealerships.

Soil Test/Laboratory	Single-product VRA**	VRA for dry fertilizer	Entire Package***
$1.60-$3.33/acre (over a four year period)	$1.00-$3.00/acre	$0-$5.00/acre	$39/acre/4 years

*Variable rate application
**computer controlled
***Includes grid sampling, variable rate fertilizer application, and maps

(Return to Table Listing.)

Table 26. Annual returns to producers for different combinations of common precision agriculture practices. The values show how these fee levels affect the profitability of each practice when used as a stand-alone technology. As practices become more integrated, returns are stabilized.

Returns to Producers	VR* P + K Application, 3-acre grid	VR application of P + K by soil type	VR of lime, 3-acre grid	VRT application of N, P, and K, plus VR planting
Low	-$7.33	-$2.11	$0.62	$11.08
High	-$13.13	$3.64	$1.31	$17.21

*Variable rate

(Return to Table Listing.)

Other fee-determining factors include the level of investment put into the technology used, the number of clientele in a region, local marketing strategies, and customer demand. Uncertainly whether precision agriculture is worth its cost stems from problems demonstrating differences, confusion generated by university studies stemming from disagreement or lack of consensus about experimental design and analytical frameworks, using input savings as the primary measure of profitability, and high expectations. Spreading costs requires that a producer sign up for programs offered by dealerships. The author concludes that the economics of precision farming are themselves site-specific.

Crop: na
Technology: VRT, grid sampling
Region: Midwest

Lowenberg-DeBoer, Jess. 1999. GPS based guidance systems for farmers. Purdue Agricultural Economics Report, December 1999, p. 8-9. (Return to REFERENCES.)

Objective: To describe the multiple uses of GPS in precision agriculture.

Methods: The author combines personal experience with testimonial to highlight the advantages of GPS, as well as the costs associated with adoption of this technology.

Results/Conclusion: Comparing GPS guidance with conventional foam marker systems:

- GPS is more accurate at higher speeds, works with spinner spreaders,
- Allows for guidance over growing crops,
- GPS is less affected by weather or uneven terrain (no bounce),
- GPS has lower recurring costs, reduces operator fatigue,
- GPS is easier to set up,
- Reduces chemical use by reducing overlaps,
- Easily generates as-applied maps, and
- Decreases the need to reenter sprayed areas.

GPS may be cost prohibitive for some producers. Custom applicators cost roughly $14,500. For producers who have GPS, guidance components cost $3000. A basic GPS system with a lightbar display (a position indicator) costs $7000. Foam marker systems costs range from $900 to $2800. The currently estimated time it would take to recover GPS costs is 3 years.

Table 27. Comparison of returns from foam marker and GPS systems.

Item	Foam marker	GPS guidance	Lightbar only
Costs:			
Purchase price, $	$1000	$7000	$3000
Useful life	5	3	3
Annualized cost, $/yr.	$264	$2815	$1206
Recurring cost:			
Foam, $/yr.	$336	0	0
Differential correction, $/yr.	0	$800	0
Annual cost, $/yr.	$600	$3615	$1206
Annual cost, $/a/yr.	$0.20	$1.20	$0.40
Benefits in reducing overlap:			
% of area overlapped	10%	5%	5%
Overlap acres	300	150	150
Opportunity costs sprayer applicator			
$/a	$4.40	$4.40	$4.40
$/yr.	$1320	$660	$660
Extra chemical/fertilizer, $/yr.	$3000	$1500	$1500
Overlap cost, $/yr.	$4320	$2160	$2160
Overlap cost, $/a/yr.	$1.44	$0.72	$0.72
GPS net benefit		**-$0.29**	**$0.52**

(RETURN TO INTRODUCTION, Table Listing, or Table 9.)

Crop: any
Technology: GPS
Region: any

Lowenberg-DeBoer, J. 1999. Adoption of GPS based guidance systems in agriculture. Successes in precision agriculture: proceedings of the 4th annual conference, Brandon, Manitoba, November, 1999. (Return to REFERENCES.)
http://dynamo.ecn.purdue.edu/~biehl/SiteFarmin/publications.html

Objective: To provide an overview of the advantages of GPS systems. Prices for this technology are provided, as well as a partial budget outlining the benefits of GPS compared to foam marker systems.

Methods: The author uses testimonial from user-groups. Some refereed journals support comparative statistics between GPS and foam systems.

Results/Conclusion: GPS is more reliable and accurate than foam marker systems. GPS also allows farmers to use specialized technologies such as spinner threaders. The technology is relatively easy to use, is less affected by weather, takes less time to set up, and allows the operator to continue work when visibility is poor. GPS systems have few to no recurring costs. Some companies presently provide free update services. The largest recurring cost for the GPS system is satellite differential correction (~\$800 year^{-1}). Many users have found this fee to be less than costs of foam. Producers owning yield monitors found that the recurring costs associated with satellite differential correction are offset when these technologies are used in tandem. Chemical waste is also reduced using GPS since it is more accurate than foam markers. A partial budget comparing foam markers and GPS includes purchase costs, machinery longevity, annualized and recurring costs, direct benefits (i.e. reduced overlap percentages as related to chemical savings), and operation costs. Partial budget results indicated a modest advantage of custom applicator GPS systems (\$14500) over foam marker (\$7000) systems (\$0.10-0.30) when custom applicators are engaged. For producers, return from GPS systems were higher than those from foam marker systems (\$0.52) when lightbar technology (\$3000) was considered distinct from GPS guidance partial budget results for GPS systems. When GPS guidance (\$7000) was compared with foam marker systems as used by producers only, returns were negative (-\$0.29).

Crop: any
Technology: GPS
Region: any

Lowenberg-DeBoer, J. and Anthony Aghib. 1999. Average returns and risk characteristics of site-specific P and K management: eastern corn belt on-farm trial results. Journal of Production Agriculture, 12(2): 276-282. (Return to REFERENCES.)

Objective: To provide an economic assessment of site-specific management (SSM) of P and K as applied to corn, soybean, and wheat production by: (1) comparing net returns of SSM managed fields compared to whole field management (WMF) strategies for P/K inputs; (2) determine whether P/K fertilizer use decreased with SSM; (3) whether risk averse farmers preferred SSM techniques over WFM strategies; (4) determine whether or not differences exist between expected returns and risk profiles when grid and soil type management strategies are compared. Grid and soil type analysis represent SSM techniques.

Methods: On-farm trial data (1993 to 1995) from six farms was compiled then used to determine the variability of returns from SSM and whole field management (WFM) fields. ANOVA was used to statistically compare differences between WFM, grid and soil type management (SSM). Stochastic dominance analysis was used to rank areas beneath cumulative distribution curves of crop returns in terms risk aversion.

Results/Conclusions: That SSM will decrease fertilizer use cannot be supported by the findings of this experiment. The total amounts of P and K applied throughout the study did not correspond with either SSM method used. In terms of average returns, fertilizer applications based on soil type had the highest returns at P = 0.25. The authors interpret the results of their mean-variance and SD analyses to indicate that these findings provide a basis (albeit tentative), for understanding the risks associated with SSM technology: SSM technology reduces risks associated with production. However, SD and mean-variance results were not significant at the 5% level of significance. (Return to Table 9.)

Crop: Corn, soybean, wheat
Technology: VRT (P and K); grid and soil type management
Region: Ohio, Michigan, Indiana

Lowenberg-DeBoer, J. 2000. Economic analysis of precision farming. In Agricultura de Precisão. Borém, Aluízio, Marcos Giúdice, Daniel Marçal, Evandro Mantovani, Lino Ferreira, and Reinaldo Vale e Gomide, eds., Federal University of Vicosa, Vicosa, MG, Brazil. (Return to REFERENCES.)

Objective: To discuss the fundamental methods for the economic analysis of precision agriculture at the farm level.

Methods: Recent literature is reviewed discussing the global state of precision agriculture. Factors to consider while studying the economic feasibility of precision agriculture are discussed as well as the conditions whereby precision agriculture technologies are likely to be adopted.

Results/Conclusion: Of central focus in this report is how to incorporate the value of information, and the costs of its collection, into a unsubstantiated reports analysis of precision agriculture. Information is viewed as any other input involved in the farm production process. The author calls for a more complete profitability analysis than previous partial budget analyses conducted for precision agriculture. This would include whole farm impacts, and impacts on the yield and cost risks producers face. The time period of the usefulness of information, such as yield maps or soil tests needs to be assessed as a depreciable asset. Information related costs include: grid soil sampling and laboratory analysis, purchase of digitized soil maps, software and computer hardware, yield map making, and training personnel to understand and implement these technologies. These costs need to be dispersed over acreage farmed, and time. Other problems associated with estimating the profitability of precision agriculture include accurately measuring yield gains; inappropriate experimental designs; detecting subtle differences in yield quality or quantity; the specificity of farming operations; the need for holistic, systematic analyses; and incorporating external, off-farm benefits. Using partial budget data from other sources, the author demonstrates that positive generated by precision farming ($47.01/ha). (Return to Table 9.)

Crop: na
Technology: VRT, precision agriculture
Region: global

Lowenberg-DeBoer, J., and Alan Hallman. 2000. Value of pH soil sensor information. Paper presented at the 5th International Precision Agriculture conference, Minneapolis, MN, July 2000. (Return to REFERENCES.)

Objective: To investigate optimal liming rate levels using an automated sensor. A unsubstantiated reports analysis is provided.

Methods: A model was developed to compare returns from pH tests conducted manually or with a machine equipped with an automated sensor. Corn yield in response to pH was modeled using a quadratic response function. A profit equation was derived to compare returns from manual and automated pH readings, and subsequent liming rates based on these findings. A grid matrix was assumed in the model. Each grid in the hypothetical field was 2.5 acres. Lime application was varied per grid based on recommendations. Uniform and variable rate applications were compared in addition to the pH sampling methods.

Results/Conclusion: Simulated results indicate that the pH sensor is more accurate than manual pH tests. Modest returns were also greater for the sensor than they were for the manual test method. However, because of the novelty of this technology, it is currently cost-prohibitive. It is more likely that producers will custom-hire this service, or rent the equipment.

Crop: corn
Technology: VRT-lime/pH
Region: Midwest

Macy, Ted S. 1993. Macy farms – site-specific experiences. Soil specific crop management: proceedings of the 1st workshop. P. 229-244. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To describe the outcomes of VRT on a working farm; specifically the effects of variable application rates, its implementation, and the financial impact this practice had on returns.

Methods: The author describes the operational procedures of a high-tech farm. A list of constraints faced by the operation impeding adoption of site-specific management technology was provided, along with the remedies used to overcome these obstacles. Using soil survey maps prepared by the USDA and grid soil fertility testing (2.5 acres/grid, 330 ft x 330 ft), the farm manager decided upon which fertilizer (N) rates should be used over 1000+ acres of crops (corn). These maps along with a GIS crop management software package was used to determine timing and rates of fertilizer application and seeding. A simple return minus costs was provided to demonstrate the profitability of site-specific management strategies for this case study.

Results/Conclusion: This farm has successfully adopted site-specific management techniques to its operation. The adoption process, according to the author, has been *ad hoc*. Incorporation of site-specific management technologies such as variable fertilizer applications and seeding entailed adapting existing technologies such as GIS, GPS, and chemical applicators to extant management practices. The farm manager developed some software programs himself, including the master controller software used to monitor field activities in-house. This program allows the controller to monitor vehicle-applicator position in real time. A budget is provided in the report. It suggests that site-specific management technology is cost effective for this operation. In fact, a total saving of $14/acre was achieved, although average yield goal of corn was reduced by 18 bushels. However, a more detailed budget would have included an itemized list of the implements bought learning curve lag times, soil sampling costs, and computer hardware and software purchased and developed.

Crop: corn, soybean
Technology: VRT
Region: Indiana

Mahajanashetti, S.B., Burton C. English, and Roland K. Roberts. 1999. Spatial break-even variability for custom hired variable rate technology adoption. Selected paper for the annual meeting of the American Agricultural Economics Association, Nashville, TN, Aug 8-11, 1999. (Return to REFERENCES.)

Objective: This report has three main objectives. First, to quantify the amount of spatial variability in fields with two or more soil types economically justifies VRT implementation. Second, how much spatial variability in a field is needed to maximize VRT. Lastly, to determine the impact of VRT on crop and input prices.

Methods: Corn and nitrogen mean prices ($2.79/bu and $0.26/lb, respectively) from the Tennessee Department Agriculture (1993-1997) were used in the model to determine returns from VRT. Estimated VRT charges were $3.00/acre. Fertilizer N application using VRT was $2.00/acre more than uniform application methods, plus an additional $1.00/acre charge for soil maps. Three land types classified fields: low-yield, medium-yield, high-yield soils. Iterations tested which combinations of soil types (as ratio percentages) yielded returns above VRT investment costs, or break-even prices.

Results/Conclusion: Fields with low- and high-yield response soils had the most frequent returns above investment. At 56% low-yielding soils (44% high yielding), returns were highest at $7.07/acre. This scenario was valid for fields with a surface area of 15-90% low-yielding soils (85-10% high-yielding soils). Eleven other economically viable combinations were determined, with returns above VRT costs ranging from $0.89 to $4.03. The medium- and high-yielding soil combination had positive returns on investment when medium-yielding soils covered 12 to 58% of the field and high-yielding soil coverage was varied. Positive returns on investment were found for low-yielding soils in combination with high yielding soils when 7 – 22% of the field was covered by high-yielding soils, and low yielding soils were varied. When medium-yielding soils were varied in combination with high-yielding soils, positive returns were generated when values ranged from 9 to 73% high-yielding soils and 20% medium-yielding soils, and 7-53% high-yielding soils in combination with 40% medium-yielding soils. The economically viable range of spatial variability decreased with decreases in corn and nitrogen prices. Conversely, increases in corn prices expanded the spatial variability of low-yielding land.

Crop: corn
Technology: VRTN, modeling
Region: Tennessee

Malzer, Gary L. 1992. The changing technology of variable rate fertilizer application. Unpublished document. Soil Science Department, University of Minnesota. (Return to REFERENCES or Table 9.)

Objective: To quantify corn yield variability, to estimate the yield response of applied N in different areas of a field, and to determine which soil quality characteristics offer the best information for determining variable N application rates. A partial budget is provided analyzing the profitability of VRT nitrogen management.

Methods: Two field locations were used in the evaluation of variable rate nitrogen application. Soil surveys were conducted at all sites within the field at a scale of 1:5000. Soil was sampled in 100-foot grid patterns (4 samples/acre). Soil pH, nitrate and ammonium N, organic C and N, and estimated of mineralizable N were determined. Four N rates were determined (the variable treatment), and compared to a uniform, conventional treatment. Three-dimensional field maps represented the spatial variability of soil fertility and N distribution and yield potential.

Results/Conclusion: Nitrogen fertilizer returns for the variable rate strategy based on yield maps and mapping units were greater at both sites ($126 and $51/acre) than returns from the conventional treatment ($108 and $27/acre, respectively). Returns from the VRT treatment where N recommendations were based on soil test were intermediate between these treatments ($117 and 30/acre).

Crop: corn
Technology: VRT-N
Region: Minnesota

Malzer, G.L., P.J. Copeland, J.G. Davis, J.A. Lamb, P.C. Robert, and T.W. Bruulsema. 1996. Spatial variability of profitability in site-specific management. Precision agriculture: proceedings of the 3rd international conference, June 23-26, Minneapolis, MN, p.967-975. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The authors evaluate the profitability of site-specific management. Profitability is defined as "the potential net return that could be expected with ideal site-specific management conditions."

Methods: Four corn 5-ha fields comprised mainly of clay and loam were treated with six N-application rates (0, 67, 101, 135, 168, and 202 kg/ha). A split-block was used as the experimental design, with each treatment replicated six times. Treatments were randomized within each block. Yield monitors were used during harvests. Economic optimum N rate (EONR) was defined as the rate at which the marginal costs of N application rates were equal to the marginal returns. Semivariograms were used to analyze spatial correlation in all fields. A simple return minus costs table evaluated the profitability of the treatments.

Results/Conclusions: Current N recommendations by the University of Minnesota overfertilized a field by 45% and underfertilized another site by 35%. Expected yields produced from both management strategies produced similar results. According to the results, the added value of VRTN is on the order of 10 to 20%. A variety of crop response functions within a given field indicated that some areas of any given field continued to respond to high N application rates, while other regions of a field needed little to no N. These response *cum* regression equations were used for EONR analyses. EONR results varied within and between sites. The authors conclude that grouping response data into response regions is only effective if accurately reflects the observed data in the sub zones that make up regions, and if it provides a reliable error estimator within the sub region. Additionally, to yield maps may be highly correlated, but differences in spatial arrangements may be different. Actual returns must include the costs of technology adoption absorbed by the farmer, and the capability of making a decision base on information generated by the activity. The authors do not include these costs, and hamstring their analysis. However, the authors state that the methodology they used to determine the EONR and profitability of VRTN is easily adaptable to other components that make up the VRTN technology bundle, especially management combinations. (Return to Table 9.)

Crop: corn
Technology: VRTN
Region: Minnesota

Mann, John. 1993. Illini FS variable rate technology: technology transfer needs from a dealer's viewpoint. Soil specific crop management: proceedings of the 1st workshop, Madison, WI, p. 317-323. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To describe how a commercial dealership made site-specific management technology more affordable to producers.

Methods: The dealership offered VRT to farmers using a two-step process: Phases I and II. Phase I included grid sampling soil test, production of a hand drawn map to show where samples were taken, a kriged map showing P, K, and pH distribution throughout the field, and a digitized map showing resulting management zones, and a kriged map showing application rates. No economic analysis was presented.

Results/Conclusion: One advantage of VRT is that it compels the salesman to interact with the producer making fertilizer plans. This, in effect, helps promote the technology as well as educating farmers about it. After three years implementing this program, the returns to the company have been middle of the road. The start-up costs were higher than anticipated, and returns have not yet compensates for this expense. The amount of business catering to VRT mapping was overestimated. However, the demand for VRT by farmers was underestimated. Notable constraints faced by the dealership include: (1) little yield information exists economically justifying VRT; (2) the project costs money; (3) a successful VRT project depends more on people, not technology; and (4) VRT must be publicized using extension or other techniques.

Crop: corn, soybean
Technology: VRT
Region: Illinois

Marks, Robbin S., and Justin R. Ward. 1993. Nutrient and pesticide threats to water quality. Soil specific crop management: proceedings of the 1st workshop. P. 293-299. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The authors describe how fertilizer and pesticide use threaten groundwater reserves, and how soil specific management can alleviate groundwater contamination.

Methods: The authors review data produced by the EPA, and other sources.

Results/Conclusion: The authors conclude that soil specific management could potentially reduce point source pollution. According to the authors, the benefits of soil specific management will not be realized unless it is regulated as policy regulating the promotion of prudent chemical input levels in agriculture. Recognizing that adoption of this particular technology is cost prohibitive, they foresee government loans to small or medium scale farmers playing a role in the dissemination of the technology. Another remedy would be creating policy that required farms to keep detailed records of chemical inputs.

Crop: various
Technology: soil specific management
Region: any

McBratney, A.B., and B.M. Whelan. 1995. Continuous models of soil variation for continuous soil management. Site-specific management for agricultural systems: proceedings from the 2nd international conference, March 27-30, Minneapolis, MN, p. 325-338. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The authors propose a model for understanding continuous soil variables and corresponding spatial heterogeneity. The model is based on fuzzy data set theory. The cost effectiveness of information derived from such a model is presented.

Methods: Conventional interpretive methods used to make recommendation for fertilizer applications were compared with soil map interpretations using fuzzy logic. Financial returns generated by a one-dimensional (conventional) model were compared to returns generated using an autoregressive (fuzzy) model. A simple return minus costs table evaluated the profitability of these diagnostic techniques.

Results/Conclusion: Simulated results indicated that returns from recommendations based on information processed using fuzzy logic were greater than returns from conventional interpretive methods. The authors conclude that fuzzy soil maps provide a more accurate description of soil variability. In addition, the authors emphasize the importance of including real time data in addition to auxiliary data in order to use soil maps effectively for site-specific recommendations. The economic analysis provided by the authors is incomplete. The only figures used in the economic analysis were returns from yield and costs of P-fertilizer. The budget did not include the costs of implementing this technology, the costs of gathering and analyzing information, or additional costs such as human capital.

Crop: sorghum
Technology: soil mapping
Region: na

McBratney, Alex B., Brett M. Whelen, James A. Taylor, and Matt J. Pirngle. 2000. A management opportunity index for precision agriculture. Proceedings of the 5th International Conference on Precision Agriculture and Other Resource Management, July 16-19, 2000, Radisson Hotel South, Bloomington, Minnesota, USA. (Return to REFERENCES.)

Objective: To develop an opportunity index (Oc) that quantifies whether site-specific management (SSM) strategies are the best way to manage farm resources based on crop and yield variability. The Oc is based on (1) the magnitude of yield variation, (2) the spatial structure of yield variation relative to the minimum capability of currently available variable rate spreader technologies, and (3) economic and environmental benefits compared to conventional management techniques. No economics are presented in this report.

Methods: Yield monitor data (1995-1999) from 20 harvests over 16 fields producing grapes, wheat, cotton, lupins, or sorghum was collected then used to establish an Oc. All crops were managed using conventional production techniques. Three general components described the model: magnitude, spatial structure, and economic/environmental benefits. Each component was broken down into a system of equations representing autocorrelated yield variations, empirical variograms, and a dummy variable representing magnitude, spatial structure, and environmental/economic benefits, respectively. The Oc is the square root of the product of each component.

Results/Conclusion: The Oc values for the 20 yield-monitored fields ranged from 2.8 to 47.2. Differences between high- and low-yielding portions of fields decreased concomitantly with decreases in Oc. The authors suggest that Oc's greater than 20 indicate that conditions may be appropriate for producers to adopt SSM technologies.

Crop: grapes, cotton, lupin, wheat, sorghum
Technology: VRT
Region: Australia

Norton, George W., Scott M. Swinton. 2000. Precision agriculture: global prospects and environmental implications. Paper prepared for the 24th conference of the international association of agricultural economists, Berlin, Germany, August 13-19, 2000. (Return to REFERENCES.)

Objective: To expand upon the definitions of precision agriculture, who is using it, and in what regions. The authors ask whether precision agriculture is suitable only in developed countries, and to what extent precision agriculture can impact markets. What environmental benefits precision agriculture will provide is examined as well. No unsubstantiated reports or partial budget analyses are provided.

Methods: The authors draw upon recent literature, data sets, and professional opinions to examine what precision agriculture-related technologies have been adopted by producers, why these technologies were adopted, and in what regions.

Results/Conclusion: There are three major components of precision agriculture: appropriate levels of information collection, information processing and interpretation, and timely implementation of information as a crop management decision at an appropriate scale. Precision agriculture technologies are development-specific or site-specific. The former focuses on predictive models such as crop growth, response to fertilizer application, or pest damage. The later relates to models that estimate technology adoption rates, factors that influence decision-making, opportunity costs, and the extent to which a producer discounts the future. The authors suggest that early adoption of precision agriculture is likely to occur in regions where agricultural land and capital are abundant. In 1996, roughly 9% of U.S. corn growers (representing 19% of the total corn acreage) had adopted one or more precision agriculture components. In 1998, Grid and map-based soil sampling techniques and yield monitoring were the most frequently adopted technologies (18%), followed by variable rate (VRT) fertilizer application (11%), 3% VRT pesticide application, and 2% for VRT seeding. Producers will adopt precision agriculture technologies when they are profitable, and adoption is more likely to occur with high value crops such as potato and sugar beets. The authors mention the importance of human capital in the adoption process, especially in terms of the level of education of a producer, and their ability to understand the value of information, and how to use it.

Crop: na
Technology: VRT
Region: na

Nowak, Peter J. 1993. Social issues related to soil specific crop management. Soil specific crop management: proceedings of the 1st workshop. P. 269-285. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The author defines the social conditions necessary for influencing adoption rates of crop management technologies: (1) the form of the technological package; (2) the physical resource base wherein the technology is to be applied; (3) the profile of human capital and farm firms in the region where the technology is to be applied; and (4) the institutional support network.

Methods: The author summarizes current research for each antecedent condition of site-specific management technology adoption.

Results/Conclusion: The author discusses in detail the four necessary antecedents of soil specific technology adoption. For explanatory purposes, each domain is broken down into subcategories. The first domain -- the nature of technology -- is comprised of an *information base*, *positioning techniques*, and *application processes*. The author points out that each of these "technology bundles" is regulated to one degree or another by the law of diminishing returns; given any context, there is a point where the costs of implementing these technologies will outweigh the benefits. The sections that follow examine the factors making up these variable socioeconomic and environmental contexts. The relation of technology to the adoption process discusses five central characteristics useful for classifying adoption of new agricultural technologies: (1) relative advantages to economic benefits and social status; (2) compatibility of the new technology to the existing array of technology; (3) how complex the new technology is; (4) the ability of the technology to be tried by farmers on a small scale; and (5) how observable results of the new technology are. The second domain – physical resource characteristics – describes the variability of soil profiles not only across the U.S., but the fact that within a given field soil profiles can be highly variable. The author alludes to the fact that the more variability there is in a given field, the greater the costs will be of soil specific management, and that soil characteristics will be the determining factor of the technology that will be used. The third domain – human capital profile – brings to attention that new technologies are always introduced into a context of pre-established routines, behaviors, and values. These factors will influence the acceptance or rejection of a new technology, as well. The fourth domain – social impacts – states that soil specific management technologies are only appropriate for high-capital, large farms unless more cost-effective technologies can be provided to small and medium sized farms. Furthermore, that farms do not operate in a vacuum (i.e. they are dependent on institutions outside of the farm firm) is brought to attention. That is, adoption of soil specific management techniques will entail a group effort involving actors representing different institutions. Of greatest concern for the author is the non-specificity of the current applications of soil specific management. Although P and K protocols are well defined, N, pesticide, and herbicide applications remain largely undeveloped.

This thorough report covers sociological and physiographic antecedents necessary for soil specific management technology adoption on a general level. Important issues omitted include learning curve lag time and associated costs, as well as individual preference profiles, and these factors influence acceptable risk levels of farmers. The author anticipates that larger farms with high outputs, greater returns, and more capital will accompany soil specific management technologies. A salient topic that could be discussed would be the externalities associated with the demise of small and medium sized farms.

Crop: corn used as reference
Technology: soil specific management
Region: any

O'Neal, Monte R., Jane R. Frankenberger, Daniel R. Ess, and James M. Lowenber-Deboer. 2000. Impact of spatial precipitation variability on profitability of site-specific nitrogen management based on crop simulation. Presented at the 2000 ASAE Annual International Meeting. Paper No. 001014. ASAE, 2950 Niles Road., St. Joseoph, MI 49085-9659 USA. (Return to REFERENCES.)

Objective: To determine how precipitation variability across space impacts farm management decisions. The economic variable used to gauge the impact of spatially variable precipitation was N-fertilization management.

Methods: Four N-management strategies were compared. Under both variable (VRT) and uniform rate (URT) N-management strategies, 40-kg of starter/no starter N application were compared. One-hectare grid cells were assumed, and yield data was simulated using DSSAT 3.5. Precipitation data included on-farm data, the closest NWS station, and the mean of the three nearest non-metro NWS stations. Resulting model parameters serviced from existing crop data were used to simulate production for 20-years with a 2-year corn-soybean rotation. Four 50-acre plots supplied existing crop data. Yield potential was estimated based on the previous five years of corn production data. One-hectare grids demarcated site-specific zones of the plots. Profitability was estimated using stochastic dominance and sensitivity tests including VRT application costs, corn price, and fertilizer costs as variables. A detailed table provided the values used to calculate profitability.

Results/Conclusion: Simulation results indicated that on-farm data was consistently the most reliable, and profitable information source regarding precipitation, and how it impacted N management decisions. The simulation model revealed that a no-start N management approach was most profitable. It also revealed that keeping track of on-farm precipitation is not profitable. The authors warn, however, that other factors more than likely contributed to this result than precipitation alone. For example, they posit that the activity of or ability to access NWS weather information and historical databases (i.e. good farm management practices) may have been more of a determining variable than precipitation itself.

Crop: corn, soybean
Technology: VRT-N
Region: Indiana

Oriade, Caleb A., Robert P. King, Frank Forcella, and Jeffrey L. Gunsolus. 1996. A bioeconomic analysis of site-specific management for weed control. Review of Agricultural Economics 18: 523-535. (Return to REFERENCES.)

Objective: To explain how quality pest management information gained by including weed distribution patterns enhances producers' weed management decisions. The economic and environmental benefit as a low input weed control strategy is examined using as bioeconomic model.

Methods: The authors modified a risk-neutral, static weed management model. Variables such as crop yield, weed control decisions variables, weed population density, herbicide effectiveness, and yields where no weeds are present represent the relationships between the biological components of weed management and the production function of crop yield. The model estimates expected net returns for a specified number of years using annual net changes in weed seed bank populations.

Results/Conclusion: Simulation results indicated that site-specific weed control is not cost effective when weeds are evenly distributed over a field. When there were low levels of patchiness, returns from site-specific management were negative. For soybeans, there was a slight return of $3.00/acre. At moderate weed levels, economic and environmental benefits are modest, yet positive for both crops. The authors assume that the returns form site-specific weed management for corn is not worth the effort when weed patchiness is moderate. At high levels of weed patchiness and pressure, variable weed control becomes economically and environmentally beneficial, especially when interventions are implemented during pre- and post-emergence stages of weed growth. The authors conclude that returns from site-specific management that is less than $3.00/acre is not sufficient to warrant the practice. The costs of information collection, time effects, and human capital were not considered in the model. How weed distribution over a field would be assessed was not addressed. (Return to Table 9.)

Crop: corn, soybeans
Technology: VRT-herbicides, simulation
Region: Minnesota

Oriade, C.A., and M.P. Popp. 2000. Precision farming as a risk reducing tool: a whole-farm investigation. Proceedings of the 5th International Conference on Precision Agriculture and Other Resource Management, July 16-19, 2000, Radisson Hotel South, Bloomington, Minnesota, USA. (Return to REFERENCES.)

Objective: To investigate the potential of precision farming (PA) as a risk-reducing, utility-maximizing tool within a whole-farm planning context.

Methods: A quadratic, risk programming model subject to constraints was devised to create a set of farm plans that border an expected value/utility limit. The function was designed to maximize gross production margins above cash expenses less the product of a risk aversion coefficient and a risk premium. The risk premium is simply the variance of net returns ($) produced under a management strategy. The risk aversion coefficient is twice a standardized normal Z value at a specified level of significance (α) divided by the standard deviation of the risk premium. Data from Arkansas wheat and cotton production from 1990 to 1997 were used to generate gross margin means and variances for risk modeling, net returns to land, risk, equipment, and other production activities. Fixed assets depreciation was not incorporated into the model.

Results/Conclusion: Under risk-neutral conditions, PA is the optimal production strategy for soybean and rice production. As the magnitude of risk aversion was increased during simulations, proportions of crop mixes planted per unit area changed as well as increases(decreases) in gross margin. This indicated that producers would be willing to accept some loss in revenue provided variation in returns decreased. The degree of gross margins of optimal management choices is inversely related to the level of risk aversion. The authors conclude that there is little evidence to suggest that PA is feasible risk-reducing strategy in whole-farm management planning. The authors suggest risk-averse farmers' act to reduce whole-farm gross margin variability. As such, PA will compliment and not replace conventional management strategies.

Crop: soybean, wheat, rice
Technology: VRT

Region: Arkansas

Pan, W.L., D.R. Huggins, G.L. Malzer, C.L. Douglas, Jr., and J.L. Smith. 1997. Field heterogeneity in soil-plant nitrogen relationships: implications for site-specific management. *In* The state of site-specific management, F.J. Pierce and E.J. Sadler, eds., p. 81-100. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The authors review the factors contributing to plant-soil dynamics in two cropping systems, and to assess how these dynamics affect prospects for site-specific N management.

Methods: The authors summarize current information regarding site-specific N management with regards to soil variability and fertilizer N efficiency. An economic analysis is presented in budget form.

Results/Conclusion: Complex relationships between edaphic and climatic factors confuse understanding of N cycling and fertilizer N efficiency. This complexity complicates production of N fertilizer responses. For example, a 37-yr study in Minnesota found that 67% of the variation in corn production was attributable to year-to-year climatic variations. Only 15% of production was attributable to direct control (i.e. fertilizer application, especially N). Thus, year-to-year yield goals prediction based on climatic variations are largely unreliable. Economic optimum yield (EONR) varied with each location. In some cases, application rates based on EONR were below the recommended rates promoted by extension agents. In other cases, rates were much higher than those prescribed for conventional application protocol (i.e. fixed or uniform rates). Returns from variable N rates applied over a field were cost-effective only in some circumstances. The authors suggest that further research in terrain and hydrologic modeling will compliment and bolster VRTN technology, especially in the field of forecasting variable N rates.

Crop: wheat, corn
Technology: VRTN
Region: Washington, Idaho, Minnesota

Pannell, D.J., and A.L. Bennett. 1999. Economic feasibility of precision weed management: is it worth the investment? *In* Precision weed management in crops and pastures. Eds. R.W. Medd and J.E. Pratley, (R.G. and F.J. Richardson, Melbourne. http://www.general.uwa.edu.au.u/dpannel/dpap99031.htm.) (Return to REFERENCES.)

Objective: To develop a framework wherein the benefits derived from precision weed management can be validly estimated. The analysis focuses on a weed management system called Weed Activated Spray Process (WASP). This technology is compared to a hypothetical technology that could be used in similar contexts, but with different results.

Methods: A variable rate herbicide applicator was tested using simulated data. A dynamic optimization model was modified to incorporate machine-specific variables such as failure to spray in indicated zones, misapplication rates, controller error, machine cost and recurrent costs, and annualized costs of the equipment. Probability distribution functions were determined for each of these parameters, then incorporated into the model. Wheat response functions based on the model were applied to a hypothetical field of 100 1-ha blocks. Variable weed densities were assigned to each block randomly. A partial budget analysis was used to determine under which scenario(s) WASP was cost effective.

Results/Conclusion: The simulated results indicated that WASP technology is not a cost-effective implement for applying variable herbicide rates over weed-infested fields. The authors suggest that their results underscore the problems variable rate applicator manufactures face when designing new precision products. Even if the WASP technology was free of any operational errors (i.e. model error parameters were set to 0), the cost of the technology itself would still exceed the benefits.

Crop: wheat
Technology: VRT, herbicide
Region: Australia

Paz, J.O., W.D. Batchelor, T.S. Colvin, S.D. Logsdon, T.C. Kaspar, D.L. Karlen, B.A. Babcock, and G.R. Paustch. 1999. Model-based technique to determine variable rate nitrogen for corn. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1279-1289, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To develop a corn crop growth model that estimates yield variability and variable nitrogen recommendation rates in the same field.

Methods: A 16-ha field was divided into 8 sections, each with 28 grids. Corn yield was measured from each of the 224 plots. Soil physical properties were determined, such as drainage corridors, soil moisture content, organic C for several soil types. Planting date, final yield, soil N, N application date and rate from each grid covering three years were obtained. The model inputs included inputs, management practices (variety, row spacing, plant population, fertilizer and application dates), and environmental conditions (soil type, daily temperature, rainfall, and solar radiation). Twenty-one N rates were evaluated. Profit (as returns from yield minus testing and application costs) per acre in terms of optimum N rates was determined during the simulation.

Results/Conclusion: Average profit maximizes at 190 lb N/acre. Yield response for 62% of the grids was increased when higher than recommended N rates were applied (190 to 200 lb N/acre). Net returns from these rates ranged from $150/grid to $450/grid on low- and high-quality grids, respectively. The authors assumed a uniform nitrate distribution in their model. This impacts the high, optimum rate observed in the simulated results. Additionally, in the economic analysis, only one variable was considered - nitrogen application rate. Economic benefits from a management practice such as variable application can be inflated when only one variable is incorporated into the model.

Crop: corn
Technology: VRTN
Region: Iowa

Pierce, Francis J., and Peter Nowak. 1999. Aspects of precision agriculture. Advances in Agronomy 67: 1-85. (Return to REFERENCES.)

Objective: To provide a historical background of precision agriculture, to summarize the current state of field, and to look forward into its possible futures.

Methods: Based on personal experience and reports from other sources directly involved with or indirectly influencing the field of precision agriculture, the authors report the current state of precision agriculture on a general, global level.

Results/Conclusion: The authors define precision agriculture as "…the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality." Several factors determine the success of precision agriculture: (1) the degree to which field conditions can be known and managed, (2) the appropriateness of recommendations based on this knowledge, (3) variable (soil, weather) and application controllability, and (4) off-farm support infrastructures. Although the concept of precision agriculture is not new, it is only until recently that computer technologies have enabled public access to GIS and GPS systems, the handling and processing of massive databases, and free information networks by way of home computers. Spatial variability is most accurately understood using GIS/GPS systems. The development of these technologies has rekindled interest in precision agriculture. However, only 31% of the 2,053,800 farms (1997) in the U.S. have home computers, and 13% internet access, and precision agriculture software is not currently available in a user-friendly, public form.

Crop: na
Technology: precision agriculture, general
Region: any

Popp, J., and T. Griffin. Adoption trends of early adopters of precision farming in Arkansas. Proceedings of the 5th International Conference on Precision Agriculture and Other Resource Management, July 16-19, 2000, Radisson Hotel South, Bloomington, Minnesota, USA. (Return to REFERENCES.)

Objective: To describe the current status of precision farming (PA) in Arkansas, the amount, sources, and efficacy of PA promotion by industry representatives and researchers, and the possible future of PA in Arkansas.

Methods: Individuals representing farmers using PA, industry representatives, and extension agents were interviewed by telephone (N = 38). Interview questions were designed to disclose (1) the extent of adoption of PA technologies in Arkansas, (2) demographic profiles of early adopters, and (3) respondents perceptions of PA, and what direction(s) the technology is heading.

Results/Conclusion: Compared to the average age of early adopters of PA technologies across the US (54 yrs.), early adopters in Arkansas averaged 45 years of age. Early adopters and industry representatives speculated that persons who adopt PA technologies expect increased revenues and decreased operation costs, and improved management capabilities. The authors speculate that PA adoption is driven by chronically low profit margins associated with some conventional management strategies, or that framers seek new technologies when current profit levels are precariously low. It might be suggested that individuals are more willing to adopt when they can financially afford to change routine management practices.

Crop: rice, corn, soybeans
Technology: PA, general
Region: Arkansas

Robert, Pierre, Scott Smith, Wayne Thompson, Wally Nelson, Dennis Fuchs, and Dean Fairchild. 1989. Soil specific management. Unpublished document. University of Minnesota. (Return to REFERENCES.)

Objective: To evaluate variable rate and conventional, uniform N application strategies. A partial budget is provided that compares the economic feasibility of VRT to conventional N management strategies.

Methods: The study area was a 70-acre field. Soil samples from three depths (0-6", 0-24", and 24-48") were tested for N, P, K, and Zn content. Test results indicated three soil fertility types (high, medium, and low). Fertilizer rates were determined from soil test results and yield potential indicated by each soil type. The conventional, uniform treatment applied 130, 40, and 30 lbs/acre of N, P, and K, respectively. Variable rate applications ranged from 50 to 140, 35 to 55, and 30 lbs/acre, N, P, and K, respectively. Another VRT treatment using the same fertilizer schedule included a herbicide. A plot receiving no fertilizer was used as a control.

Results/Conclusion: Net returns above the check plot were \$91, \$96, and \$111 for conventional, VRT, and VRT with herbicide treatments, respectively. Corn yield was 133, 139, and 145 bu/acre for conventional, VRT, and VRT with herbicide treatments, respectively. There was an increase of $20/acre with VRT inputs versus conventional applications.

Crop: corn
Technology: VRT-N
Region: Minnesota

Rejesus, Roderick M., and Robert H. Hornbaker. 1999. Economic and environmental evaluation of alternative pollution-reducing nitrogen management practices in central Illinois. Agriculture, Ecosystems and Environment 75: 41-53. (Return to REFERENCES.)

Objective: To examine the economic and environmental impacts of site-specific N management (VRT) and N-application timing used on continuous corn production systems. Of specific interest was whether these practices decreased nitrogen effluent loads from agricultural practices into the Lake Decatur watershed.

Methods: An EPIC model was calibrated to simulate a continuous corn production system over a 40-year cycle. The model was also calibrated according to local hydrological characteristics and N application rates and timing based on five soil types. Nitrogen rate levels considered were 0- to 252-kg/ha at 28-kg/ha intervals. EPIC results were compared with existing studies that provided on-site monitoring data. Profitability was determined using marginal analysis. The marginal revenue from an additional unit of nitrogen was compared to the marginal costs of the application of that extra unit.

Results/Conclusion: The authors found when N application rates increase, the mean and variability of pollution also increases. Mean N pollution increases most rapidly after optimal fertilizer recommendation levels have been surpassed. Results demonstrate that VRT can decrease the mean and variance of nitrate pollution while concomitantly improving profitability relative to fertilizer application. As such, the authors imply that VRT management might be preferable to risk-averse producers. The authors conclude that VRT provides a win-win situation since producers' benefit by decreasing inputs (thereby increasing profits), and reduce effluent discharge into the environment.

Crop: corn
Technology: VRT-N
Region: Illinois

Robert, M., A.Le Quintrec, D. Boisgontier, and G. Grenier. 1996. Determination of field and cereal crop characteristics for spatially selective application of nitrogen fertilizers. Precision agriculture: proceedings of the third international conference, June 23-26, Minneapolis, MN, p. 303-313, ASA-CSSA-SSSA. (Return to REFERENCES.)

Objective: The effects of potentially usable factors that could aid in the design of VRTN application systems were quantified. The VRTN methods examined by the authors were compared to conventional N application practices. No economic analysis was provided.

Methods: A 16 and 18-ha field were divided into 111 and 126 grids respectively, each grid with a surface area of 144 m^2. Soil depth, N, pH, and organic matter test were conducted on each grid. During the growing season, each cell was divided into two sections. One section implemented VTRN; the other section was managed using conventional methods. During the growing season, the number of plants per grid was measured. At harvest, gross yield per treatment was determined. No yield sensors were used.

Results/Conclusions: There were no significant yield differences observed between the two experimental fields. Using step-wise regression, pH was eliminated from then model, while soil depth and stone coverage remained. Of the factors tested, soil depth and crop yield had the largest coefficient of correlation. Presence or absence of stones was the second most important factor useful for explaining crop yield variability. When conventional and VRTN application methods were compare, there were no differences in crop yield. The authors conclude that yield mapping is insufficient when used alone to manage VRTN, and that models designed for whole fields are not precise. Although the data was not presented, the authors end by stating that gains to the farmers would only be about $40.00/ha when comparing VTRN to conventional nitrogen application methods.

Crop: wheat
Technology: VRTN
Region: France

Roberts, Roland K., Burton C. English, and S.B. Mahajanashetti. 1999. Hypothetical example of evaluating economic benefits and costs of variable rate nitrogen application. Paper presented at the annual Meeting of the Southern Agricultural Economics Association, Memphis, TN, January 80 - February 3, 1999. (Return to REFERENCES.)

Objective: To highlight the possible economic benefits of variable rate N application compared the costs of hiring those services by demonstrating the effects of changing net input-output returns, field spatial variability, and yield response functions in a simulation model. The information required to elicit and monitor these changes is incorporated into the unsubstantiated reports framework as well.

Methods: The hypothetical corn yield function representing low, average, and high yielding field zones are used to generate N-recommendations. Variable rate and uniform rate application technologies are compared. Corn and N-fertilizer prices ($0.22/lb and $2.42bu/acre, respectively) were obtained averaging 1986-95 data, and used in a partial budget analysis. A sensitivity analysis was conducted to show how changes in corn and nitrogen prices, field spatial variability, and yield response function parameters influence returns above variable costs for VRT and uniform application rate technologies.

Results/Conclusion: As the proportion of low-fertility land increases, the more profitable variable rate N application becomes. However, the converse is true. Ranges between 15% poor and 85% high-yielding land tend to be the profitable ratio ranges in this example. When poor-yielding soils covered 58% of the field, optima are maximized. Using sensitivity analysis, the authors conclude that larger differences between marginal products increase the likelihood that VRT-N will be profitable. This leads to wider choice of variable rate services options a farmer can select. The authors end by stating that positive VRT returns are realized on field-by-field bases, only. But precision agriculture has the potential to provide producers with more management decision opportunities, increase yield, and reduce N-fertilizer input costs.

Crop: corn
Technology: VRTN
Region: Tennessee

Sawyer, J.E. 1994. Concepts of variable rate technology with considerations for fertilizer application. Journal of Production Agriculture, 7: 195-201. (Return to REFERENCES.)

Objective: To summarize the concepts defining variable rate technology. The promises and constraints of the technology are discussed. A cursory partial budget is provided comparing net returns from field managed using conventional, uniform fertilizer application practices, and variable rate management strategies.

Methods: The author combines personal experience and findings from other researchers to describe the components of VRT, and the forms the technology may assume as it evolves in the agro-industrial farming context.

Results/Conclusion: The author summarizes the principle issues and expectations related to VRT. Consumers expect positive returns, and there are environmental benefits assumed to go hand-in-hand with VRT. These expectations hinge upon being able to identify spatial variability of fertility zones within a field, then being able to apply just enough fertilizer to those zones to maximize crop output. For example, high fertility zones may receive more fertilizer, while low fertility zones may receive less. Intermediate fertility zones may receive rates recommended by university or county extension offices. That variable rate application is more efficient than uniform fertilizer application strategies has been demonstrated. It is also assumed that by applying less N fertilizer, for example, there are quantitatively fewer nitrates leached into groundwater basins or streams. By maximizing the amounts within field fertility zones, it is assumed that the whole field management is optimized because of VRT efficiency. Externalities caused by non-point source pollution are also diminished hence the environmental benefit. In the case of VRT as optimizing farm resources and its economic feasibility, the results are mixed. Uncertainty still resounds which soil sampling methods are best under which circumstances, which crops VRT works best with, soil sampling techniques and sampling density, whose yield response functions best describe production realities, and what yield goal levels are reasonable using this technology. In the latter case, there is little data to support the assumption that VRT is environmentally beneficial.

Crop: any (corn used as an example)
Technology: VRT
Region: all

Schmitt, Michael, and Dean Fairchild. 1991(?). Variable rate fertilization-can the technology pay for itself? Unpublished document. Department of Soil Sciences, University of Minnesota, St. Paul, Minnesota. (Return to REFERENCES or Table 9.)

Objective: This document describes one of the first evaluations of VRT using an experimental design. The objective of the research was to evaluate the efficacy of soil evaluation techniques, yield potential levels based on these results, and how fertilizer recommendations based on these parameters affected yield and profit.

Methods: Treatments included a check, or control plot, a conventional (uniform rate) treatment, and a variable rate treatment. Fertilizer recommendations were based upon soil sample results collected using grid sampling, and yield potentials identified with each identified soil zoned. Data was collected from two crop cycles.

Results/Conclusion: Returns were greatest for variable rate treatments for both growing seasons. Returns to VRT were $326 and $204/acre, $315 and $197/acre for conventional treatments, while check plot returns were $184 and $118/acre for 1989 and 1990, respectively. Overall, lower N rates were applied to plots fertilizer using VRT. Profit analysis included the price of VRT applicators (range $15 000 to $40 000), map making ($0.40/acre), soil surveys ($1/acre), and custom application charges ($4.50 - 6.40/acre), which is close to $1-2/acre more than conventional application charges.

Crop: corn
Technology: VRT
Region: Minnesota

Schnitkey, G.D., J.W. Hopkins, and L.G. Tweeten. 1996. Precision agriculture: proceedings of the 3rd international conference, June 23-26, Minneapolis, MN, p.977-987. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To evaluate returns of variable rate fertilizer application strategies on corn-soybean rotation fields.

Methods: Three fertilization strategies were evaluated: uniform rate, information-based, and variable rate strategies. The information-based strategy implements knowledge about field fertility found by conducting soil tests. The variable rate technology implements the information derived from soil tests, then applies fertilizers at rates prescribed by management zones. Return differences were compared for each treatment. Fertilizer carry-over effects were incorporated into the model during analysis.

Results/Conclusion: Revenue increased when field fertility information was known. On average, implementing this information by varying fertilizer application rates further increased revenues compared to control plots. Using information-based fertilization recommendations increased profit by $5.74/acre. When these returns were combined with precision agriculture technology, profits further increased by $3.28/acre. (Return to Table 9.)

Crop: corn, soybean
Technology: VRT
Region: Ohio

Silsoe Research Institute. Date Unknown (1999 ?). Yield mapping and precision farming : an appraisal of potential benefits based on recent research and farmer experience. Silsoe Research Institute (SRI), Wrest Park, Silsoe, Bedfordshire, MK45 4hs, Tel : 01525 860000. (Return to REFERENCES or Table 9.)

Objective: To summarize the benefits associated with yield mapping in precision agriculture.

Methods: Testimonial, anecdotal evidence, and research are used to describe how yield mapping can be integrated into the decision-making processes characteristic of precision farming. Examples include VRT-N, P, K, and weed management, understanding soil types, and how coordination of these inputs can be improved using yield mapping. The objective includes building and managing a farm-specific database that can be periodically updated using yield mapping.

Results/Conclusion: Using a yield map, VRT-P, K application costs in low-yielding areas of one site were reduced by $19.50/ha. Application costs only increased by $7.50. Yield maps and associated technologies are flexible enough to be adapted for other production activities. For example, on the same site, yield maps were also used to vary seeding rates. On another site, yield mapping allowed for the variable application of fungicide. The area that would have received fungicide application using conventional spraying methods was reduced by one-fourth, which translated into input savings. Yield mapping increased gross margins by $288.75/ha when applied to VRT-liming at another Berwickshire farming company producing barely and rapeseed. The article describes why yield map are a good place to begin precision farming practices. Yield maps are not expensive, costing between $3-4.50/ha. However, the information they provide is applicable to a variety of problems. Once problems are identified, a partial budget can be constructed to evaluate whether VRT in a specific area would be profitable. According to the document soil variation is the main influence of crop yield. Knowing where low- and high-yielding areas exist facilitate identification of fertility zones.

Crop: mixed
Technology: yield mapping, VRT
Region: general

Snyder, C., T. Schroeder, J Havlin, and G. Kluitenberg. 1996. An economic analysis of variable arte nitrogen management. Precision agriculture: proceedings of the 3rd international conference, June 23-26, Minneapolis, MN, p.989-998. ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The authors develop and economic framework to facilitate the adoption process and development of site-specific management technologies. Site-specific agronomic data is used.

Methods: Variable and uniform N-application strategies were compared over a three year study on two sites. Soil samples collected on a 55 by 55m grid determined organic matter, pH, elevation, and soil texture. Spatially distributed yield goal and soil nitrate were used to make N rate recommendations. Yield goals were based on real yield maps. Based on a model developed by the university soil-testing lab, six N rates were determined, and then applied to experimental plots at rates of 146, 179, 213, 269, and 314 kg/ha. Variables included in the statistical analysis were yield, crop year, available N, N over-application, N under-application, elevation, change in elevation, organic matter, pH, soil texture, and nitrates. The estimated charge for VRT was $42.76/ha (including lab analysis, labor, and data management costs).

Results/Conclusions: Correlation between variables were unique to each site, excluding relations between N over-application and yield. For every kilogram of N over-applied, yield decreased by 0.016 Mg/ha. The estimated amount of total N applied to fields was always less for VRT than for uniform application strategies. VRT profitability results were different for both sites and both years. Both sites enjoyed one year (out of two) with return from VRT management. The authors assume these results reflect differences in growing seasons. (Return to Table 9.)

Crop: corn
Technology: VRTN
Region: Kansas

Sobolik, Chris J., Alan Dzubak. 1999. Evaluation of commercial cotton yield monitors in Georgia field conditions. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1227-1240, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To evaluate the performance of two commercial yield monitor systems. A brief economic analysis is provided.

Methods: Four sites were used in this study. Two commercial yield monitors were tested. The cost of the first system was $10,630 and $6,130, with and without GPS equipment, respectively. The second system cost $14,383 and $10,083 with and without GPS, respectively. Analytical software for both systems cost an additional $2000. After calibration, sites were harvested and the accuracy of the yield monitors was compared.

Results/Conclusion: The researchers and producers involved in the study identified flaws in both systems. First, the cost of this technology were considered prohibitive by the producers, even though the results (as yield maps) were accurate and deemed potentially useful. Second, the time it would take to learn how to maintain, manage, and operate these systems, and associated software, were considered daunting by researchers and producers as well. The accuracy of both systems was greater when machines were calibrated to scan larger field units than smaller sections. This data was found insufficient for analyzing site-specific accuracy. For cotton, yield monitors are still in the research and development stage. Costs of the yield monitors was included in the report. However, they were not compared with production data. Compiling historical data from each of the three would provide data whereby returns from this technology over time could be projected.

Crop: cotton
Technology: Yield monitoring
Region: Georgia

Solohub, M.P., C. van Kessel, and D.J. Pennock. 1996. The feasibility of variable rate N fertilization in Saskatchewan. Precision agriculture: proceedings of the third international conference, June 23-26, Minneapolis, Minnesota, p. 65-73, ASA-CSSA-SSSA. (Return to REFERENCES.)

Objective: The objective of this research is to understand the influence landscape position has on the physical properties of soils, and what implications this has for managing soil productivity using techniques like VRTN.

Methods: A 7.4 ha wheat field was divided into 12 10 x 620 m rows. Each strip was further broken down into 10 x 10 m grids. Soil testing was carried out before the experiment. Each grid was assigned to one of three management options based on topographical characteristics and assumed "wet' and "dry" year scenarios: higher elevations in the field received 90 kg/ha of N, while low lying areas received only 30 kg/ha. The converse was true for "dry" season scenarios. The conventional rate was 60 kg/ha. Crop yield was also measured.

Results/Conclusions: Grain yields did not vary with fertilizer treatment, especially in low-lying depressions. However, the authors note that grain yield was 10 bushel/acre more in low-lying areas than in higher elevations. "Wet" and "dry" scenarios and corresponding fertilizer rates were not cost effective. However, different fertilizer rates were cost effective when landscape was considered. Although the authors provide an economic analysis relating to their work, it is not clear whether or not the results support the use of VRTN from a research perspective or that of a working farm. Furthermore, the analysis is based only upon one year's worth of data. A more accurate assessment could be made with at least three consecutive years of data. Additionally, the yield results may be confounded since P was added to the experimental units during the experiment, as well as N. Whether of not this made a difference was not brought to attention.

Crop: wheat
Technology: VRTN
Region: Saskatchewan

Swinton, Scott. 1997. Precision farming as green and competitive. Paper prepared for the AAEA/AERE/IAMA Workshop on Business-Led Initiatives in Environmental Management: The Next Generation of Policy, Toronto, July 26, 1997. (Return to REFERENCES.)

Objective: To define precision agriculture, examine its record for decreasing farm chemical effluent, and evaluate its role in increasing production efficiency.

Methods: The author uses personal experience to define precision agriculture, and the role it could play in improving environmental quality while increasing farm production efficiency and competition amongst agribusiness dealerships.

Results/Conclusion: Eliminating waste is at the heart of precision agriculture. From here, production can be optimized and steps towards improving the environment can be taken. (However, precision agriculture does not necessarily reduce input use.) Precision input management is practiced using a variety of methods: site-specific management, grid soil sampling, variable rate technology, GIS and GPS systems, developmental stage-based management (managing crop life cycles), and integrated pest management. None are truly stand-alone, and efficacy of each activity is enhanced in combination with other activities. For example, variable rate fertilizer application is not possible without grid based soil sampling, and is made more efficient using GPS guidance. The second objective of precision agriculture is the substitution of physical inputs with information. When weed distribution and density is known throughout a field, spot spraying can take the place of whole-field treatments. In terms of beneficial environmental impacts precision agriculture may have, data is scarce, if not nonexistent. Currently, only results from simulated are available for speculation. In terms of competition, precision agriculture is a relatively new industry where a variety of services can be marketed. Services such as soil sampling, lab analysis, custom fertilizer application, map making, and data collection and management can be offered on a competitive basis. Of course, this would in effect strengthen the already strong, vertical bond between producers and agribusiness representatives. Cooperatives and large agro-industrial firms will most likely realize these relations. Producer adoption of precision agriculture has been slow because of high costs of data collection, machinery, grid soil sampling, variable applicators, consultant fees, and the uncertainty of returns. However, yield monitors are currently at the forefront of the adoption wave. This is encouraging for precision agriculture since yield monitors provide a foundation for understanding field spatial variability.

Crop: na
Technology: precision agriculture/general
Region: any

Swinton, Scott, Stephen B. Harsh, and Mubrariq Ahmad. 1996. Whether and how to invest in site-specific crop management: results of focus group interviews in Michigan, 1996. Staff paper 96-11, Department of Agricultural Economics, Michigan State University, East Lansing, MI., 1996. (http://agecon.lib.umn.edu/msu/sp97-37r.html.) (Return to REFERENCES.)

Objective: To learn about producers' experiences with site-specific management, and to discover what information they felt important to make decisions whether to invest in site-specific equipment or services.

Methods: A series of focus groups consisting of farmers having some, little, or no experience with site-specific management (SSM). All invitees were interested in the subject. University staff led focus group sessions. Questions were presented to farmers representing each SSM experience level. Interview results include each response frequency count.

Results/Conclusion: Respondents pointed out that adopting some SSM components obliged them to purchase additional components to maximize the utility of the original equipment. For example, growers who had purchased yield monitors, and wished to analyze their own data were compelled to buy computer hardware, software, and peripherals. The alternative purchasing these products is to hire a consultant to analyze data. Other costs incurred adopting SSM components included time down for learning how to use new equipment, component incompatibility (especially with software), and equipment obsolescence. The panel also noted unreliability of some SSM equipment, as sometimes-new equipment such as yield monitors) have not undergone rigorous field trials before they enter the market. For respondents who were interested in adopting SSM technology, this was seen as one of the major risks associated with SSM. Benefits from SSM were expected more often than realized, according to panel members. For example, farmers expected tangibly noticeable results from variable seed, lime, and N and P fertilizer application. (Although only one farmer in the discussion group had been using these management strategies.) Framers were also willing to experiment with some of the technologies, such as yield monitors, variable rate applicators, and grid sampling. All participants agreed that SSM technologies would provide a sense of where the farm firm was at any specific point of time during the growing season, or over a decade. A equipment cost range list is provided in the text.

Crop: all

Technology: VRT
Region: Michigan

Swinton, S.M., and J. Lowenberg-DeBoer. 1998. Evaluating the profitability of site-specific farming. Journal of Production Agriculture 11(4): 439-446. (Return to REFERENCES.)

Objective: To provide information about site-specific management (SSM), especially variable rate technology (VR) and yield mapping, in terms of its profit potential using partial budgets. The report uses actual data from nine different farm firms growing wheat and/or barley, sugar beets, or corn.

Methods: After a description of the technological components that make up the SSM composite (for example, GPS, GIS, variable rate applicators, sensing technologies, yield maps and yield monitors), the authors conduct a profitability analysis using a partial budget for variable rate technology.

Results/Conclusion: Experimental designs to appropriately evaluate SSM profitability are lacking. In the interim, partial budgets are useful for analyzing positive returns from SSM. The main partial budget line items guiding VR unsubstantiated reports analysis are inclusion of the increased costs associated with soil sampling and variable fertilizer application, added information costs, difference in fertilizer cost, and revenue changes caused by crop yield. The nine case studies used to generate partial budgets included the crops corn, wheat, barley, and sugar beets. Of the four crops, VR was not profitable for wheat and barley. Results were mixed for corn, but returns were positive for VR-managed sugar beets. Not surprisingly, high value, high-yielding crops are more economically responsive to VR than lower value, lower yielding crops such as wheat and barley. Of less importance are savings from reduced fertilizer use, since many of the fertilizers used are relatively inexpensive. There exists no profitability information in the literature for four reasons. Interpretation of yield maps is oftentimes subjective. Secondly, yield maps offer other profit opportunities besides VR. Thirdly, it is difficult to establish cause-effect relationships between crop yield and yield maps. Lastly, benefits of VR cannot be attributed solely to yield maps since farms are embedded in wider, socio-economic and ecological beyond the farm borders. Yield maps are probably more important for activities other than VR. In terms of VR, the upshot is that yield maps do not provide as high a quality of control-information that other analysis (such as grid sampling) do. However, yield maps are useful for monitoring whole field improvements, and can lower on-farm experimentation costs during harvest. The authors recommend that individuals considering adopting SSM proceed with caution since profitability results are highly variable, and that during this early stage of development, technologies still need to be perfected. Information will increase profitability through changed decisions, but only if the consequences of actions guided by those decisions have beneficial outcomes. Other unforeseeable factors impossible to take into account may negatively influence an outcome. Looking backwards, the information used to make a decision may have been correct, all things being equal. The blame of the information-providing model would rest in its inability to account for risk, and more importantly uncertainty.

Crop: wheat, barley, sugar beets, or corn
Technology: VRT, yield mapping
Region: Western U.S., Mid West

Swinton, Scott M., and Kezelee Q. Jones. 1999. From data to information: adding value to site-specific data. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1681-1692, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: The authors develop a conceptual model to examine differences between the quality of soil information generated by sampling or remote sensing techniques, when sensing is more profitable than sampling, and when sensing generate more consistent net returns than sampling.

Methods: First, the authors provided a linear production function for corn, incorporating terms representing N fertilizer costs. Then, the authors derive profitability models for N recommendations based on sampling or sensing information. These models place particular emphasis on profitability variance terms as they estimate the degrees of risk involved with these technologies in terms of net returns generated using these technologies.

Results/Conclusion: There were no results based on data presented in the report. Instead, conclusions relied strictly upon mathematical proofs. The authors conclude that soil sensing techniques generate more accurate information than sampling methods. However, the value of one technique cannot be ranked above the other since farmer risk preference governs which technology will finally be implemented. Payoffs from sensing are greatest when: (1) sensing results generate highly accurate soil profile information; (2) when there are time constraints; (3) where there are high degrees of field variability. Sampling techniques were profitable when: (1) sensor equipment is faulty; (2) there are no time constraints; (3) spatial variability is not as great.

Critique: The profitability analysis provided by the authors was purely theoretical. No actual or even simulated figures were used to support or verify the assumptions of the model they provided.

Crop: na
Technology: VRT, modeling
Region: na

Swinton, S.M., and J. Lowenberg-DeBoer. 1998. Profitability of site-specific farming. Site-Specific Management Guidelines, Potash and Phosphate Institute Series SSMG-3, South Dakota State University. (Return to REFERENCES.)

Objective: The authors' ask when variable rate application has been profitable, and under what circumstances. Additionally, the utility of yield mapping as a profit-increasing technology is examined.

Methods: The authors' use partial budgets to analyze the value of yield-monitoring, map making, and variable fertilizer application. A detailed list of the components that make up each of these technologies is included.

Results/Conclusion: Partial budgets focus only on items whose costs change as a result of the introduction of a new technology. Losses (increased costs plus reduced revenues) are subtracted from gains (reduced costs plus increased revenues). A comprehensive partial budget includes all variable and cash costs. Oftentimes, costs associated with training, conferences, seminars, and workshops are omitted. These costs should, like other variable costs, be averaged over time and acreage. Long-term costs should be adjusted to reflect costs over one year. Since site-specific information is useful for several years, its collection costs should be spread over its entire useful life just as for any depreciable asset. Profitability is increased by information only if it changes decisions, and yield-gains are the primary in-field source of increased revenue expected from site-specific management. Variable revenues need to be added in the partial budget. Net-present value, sinking fund approaches can be used to annualize equipment costs based on a percentage over time. This includes yield monitors, spreaders, and GPS systems. Annualized costs need to be spread across acreage and time as well. The authors conclude that variable rate technology is profitable with high-value crops such as potatoes and sugar beets. Reports indicate mixed results with corn. Barley and wheat are not generally responsive to VRT. Profitability of yield mapping has proven more difficult since results (maps) are oftentimes open to subjective interpretation, and what a decision-maker decides to do with the information. Yield maps generate information not only about yield, but also about soil fertility, topography, and other production-related variables.

Table 28. Partial budget analysis of GPS-Yield Monitor and GPS-fertilizer application systems.

Item*	Unit	Quantity	Price	Amount
Change in yield	Bu/A	15.32	$2.30	$35.24
Change in equipment cost per acre - 10% discount rate, 3 year depreciation				
Yield monitor	Item	1	$4000.00	$1.33
GPS	Item	1	$6000.00	$1.99
Planter, controllers	Item	1	$5000.00	$3.32
Microcomputer, printer	Item	1	$3000.00	$1.99
Total increase in equipment cost				**$8.62**
Change in fertilizer cost				
Nitrogen	Lb/A	-0.044	$0.25	-$0.11
Phosphorus	Lb/A	-14.66	$0.30	-$4.40
Potassium	Lb/A	-3.33	$0.13	-$0.43
Sulfur	Lb/A	2.17	$0.21	$0.46
Zinc	Lb/A	0.11	$2.36	$0.26
Boron	Lb/A	0.05	$7.17	$0.36
Total change in fertilizer cost				**-$3.87**
Change in seed cost	Bags/A	0.01	$90.00	$0.48
Change in soil sampling cost	Acre	1	$5.00	$5.00
Change in fertilizer application cost	Acre	1	$5.00	$5.00
Consulting fee	Acre	1	$0.50	$0.50
Net return to site-specific management	**Acre**	**1**		**$19.50**

*Source: Finck, Charlene. 1998. Precision can pay its way. Farm Journal, Mid-January, 1998, p. 10-13. (Return to ECONOMIC METHODS, HUMAN COSTS, Table Listing, or Table 9.)

Crop: any
Technology: VRT, partial budgets
Region: any

Swinton, Scott, Mubariq Ahmad. 1996. Returns to farmer investments in precision agriculture equipment and services. Staff Paper 96-38, Department of Agricultural Economics, Michigan State University, East Lansing, June 1996. (Return to REFERENCES.)

Objective: Based on interviews and focus group results, the authors identify what producers feel affects profitability of site-specific management. These findings are related to investments made by producers. Inferences are then made about the return potential of precision agriculture given this context. The authors outline additional factors that should be considered when determining the benefits of site-specific management.

Methods: A series of focus groups including farmers interested in or already practicing some form of site-specific management. The groups also included agribusiness representatives. Producers participating in the meetings farmed 380 to 3,000 acres. All were cash crop farmers.

Results/Conclusion: Grid soil sampling costs were the major concern of producers in terms of costs ($4.75 to $10.00/acre). Other concerns were unanticipated costs associated with adopting site-specific management practices, such as consulting fees, data collection and analysis, or computer hardware and software. Producers who had purchased $3000 to $9000 yield monitoring systems found they had to invest an additional $1000 for software capable of analyzing generated data. Computers capable of operating the software became another additional, unanticipated cost. Learning how to use these products cost producers in terms of time away from daily work tasks. Some complained that technical support for these additional items was inconsistent or absent. Farmers expected site-specific management to increase yields by varying seed population and planting density, variable rate liming, and increased control of nitrogen and phosphorous fertilizers. Risk management was another factor respondents felt site-specific management could address. These expectations were more often not met than realized. Participants stated they were willing to experiment with site-specific management so long as the costs were modest. Farmers who had purchased yield monitors were hesitant to invest in grid soil sampling and variable rate technologies until they had more reliable proof of benefits associated with these technologies. The authors conclude that prior economic analyses of precision agriculture have failed to take into consideration the hidden costs of technology adoption, namely learning, obsolescence of information and machinery, incompatibilities, and recurring costs. Additionally, definitions of benefits have been restricted to increased yield and reduced input costs. Additional benefits such as fertilizer carry-over effects, the flexibility of site-specific machinery as tools capable of carrying out multiple tasks, the long-term value of yield maps, and off-farm value of information applicable to rent negotiation or data for seed or herbicide companies should be included into partial budget analyses. Risk reduction should also be factored into any unsubstantiated reports analysis, break-even, or partial budget analysis, along with any potential environmental benefits.

Crop: na
Technology: VRT, precision agriculture/general
Region: Midwest, Michigan

Swinton, S.M., K.Q. Jones, N.R. Miller, O. Schabenberger, R.C. Brook, and D.D. Warncke. 2000. Comparison of site-specific and whole-field fertility management in

Michigan soybeans and corn. Proceedings of the 5th International Conference on Precision Agriculture and Other Resource Management, July 16-19, 2000, Radisson Hotel South, Bloomington, Minnesota, USA. (Return to REFERENCES.)

Objective: Using data from two commercial farms, the authors compare variable rate and whole field applications of P, K, and lime. Data was analyzed using spatial econometric techniques. Profitability was measured subtracting variable costs from gross production margin.

Methods: Two 16.2-ha plots under corn-soybean rotation schedules on different farms were each sub-divided into four blocks. Each block was sub-divided into four strips. Site-specific or whole-field P, K, and lime applications were randomly assigned to each strip. Soybean rotations were followed by corn, or vice versa depending on the site. Soil profiles were characterized at each site. Phosphorous, potassium, and lime were applied based on yield goals specific to each site and respective sub-blocks. Whole field application costs ($7.41/ac) were twice site-specific application costs ($14.82). Custom GPS soil sampling and map making ($8.65/ha) was annualized over three years at a 10% discount rate ($3.48/ha). Lime costs and application was annualized over five and seven years at 10% for both sites ($0.21 and $0.26, respectively). Crop prices from 1998 were used in profitability analyses.

Results/Conclusion: Combined results of two growing seasons failed to indicate that yields, savings, profitability, or yield stability benefits were produced by site-specific management (SSM) treatments. There was no measurable yield gain from SSM treatments, and SSM profitability (as gross margin over variable costs) was not statistically different from whole field application strategies. The authors conclude that benefits from SSM will only be realized over time, not two growing seasons. Further more, the fields used in the study site had been well managed to begin with.

Crop: corn and soybean
Technology: VRT-P, K, and lime
Region: Michigan

Taylor, Randal K., Mark D. Shrock, Naiqian Zhang, and Scott Staggenborg. 2000. Using GIS to evaluate the potential of variable rate corn seeding. Paper presented at the AETC meeting, Paper N° 00AETC105, sponsored by the ASEA, 2950 Niles Rd., St, Joseph, MI 49085-9659 USA. (Return to REFERENCES or Table 9.)

Objective: To determine optimal variable seeding rates for corn using GIS systems which included soil electrical conductivity measurements, elevation, and yield potentials. A brief partial budget was used to determine the economic feasibility of the combination of these technologies *a propos* to VRT-seeding.

Methods: Using a differential GPS unit, soil electroconductivity was used to determine topsoil depth at three different test sites. Yield potential, seeding rate, soil EC, and relative elevation data layers were interpolated in 3d map form. This information was translated into a grid composed of 4.57 m blocks (to match the harvest width). Soil EC was classified into five levels. A yield response function regressed EC values to determine seeding rates for each zone. VRT-seeding rates were compared to uniform seeding rates of 26 000 seeds/acre and optimal seeding rates estimated from yield data.

Results/Conclusion: Corn yields and gross returns were higher under the VRT-seeding strategy than the URT method across all sites. However, when application and information costs were considered, the net returns from VRT were inferior to the URT seeding strategy. The authors suggest that unless better, more cost-effective soil/yield potential diagnostic tools become available, VRT-seeding using these technology combinations is not currently profitable.

Crop: corn
Technology: VRT-seeding
Region: Kansas

Thompson, Wayne H., and Pierre C. Robert. 1995. Evaluation of mapping strategies for variable rate applications. Site-specific management for agricultural systems: proceedings from the 2nd international conference, March 27-30, Minneapolis, MN, p. 303-323. ASA/CSSA/SSSA. (Return to REFERENCES or Table 9.)

Objective: Efficacy of two mapping strategies - soil survey and grid sample methods - were compared as tools used during variable rate application of nitrogen, and conventional, uniform application of nitrogen.

Methods: Remote sensing images of an 11-acre plot were digitized and transformed into a contour map indicating field fertility zones and drainage corridors. A laser theodolite was used to geo-reference the plot and to specify elevation variations across the field. These data were kriged, then loaded into a GIS database. Four treatments were a control receiving no nitrogen, a conventional nitrogen rate applied uniformly, variable N-applications based on grid sample (kriged) results, and variable N-applications based on soil survey results. Treatments were applied randomly across 16 strips on the experimental plot. Each treatment was replicated four times. A partial budget evaluated the profitability of the mapping strategies.

Results/Conclusion: There was statistical variability within each of the treatments. However, there were no appreciable returns from either VRTN mapping strategies when compared to the uniform rate treatment or the control. The authors suggest that variable rate technology is not an appropriate management strategy for this particular field.

Crop: corn
Technology: VRTN, mapping
Region: Minnesota

Thrikawala, Sunil, Alfons Weersink, Gary Kachanoski, and Glenn Fox. 1999. Economic feasibility of variable-rate technology for nitrogen on corn. American Journal of Agricultural Economics 81: 914-927. (Return to REFERENCES.)

Objective: To determine the economic feasibility of variable rate nitrogen application technology to corn. Three application strategies are compared: VRTN, uniform rate, and split nitrogen rate applications. The authors characterize the additional cost of VRTN and the settlement between efficiency gains from VRTN (in view of increased yields and/or reduced fertilizer costs).

Methods: A simulation model compared unsubstantiated reports trade-off between three fertilizer application strategies: a constant, uniform rate strategy; a non-GPS dependent variable rate application strategy where three possible rates are available to the farmer while spraying; and a VRT strategy where GPS is used and more than three rates can be applied.

Results/Conclusion: Fertilizer effectiveness increases when the number of management units (field variability) increases because precise amounts of fertilizer can be determined for specific locations in a field thereby increasing yield and reducing fertilizer input costs. When there was a decrease in average fertility, an increase in revenues was observed from fertilizer application. This relation is not linear and reflects diminishing marginal productivity of the fertilizer term in the yield grain function. Fertilizer costs were inversely proportional to soil fertility. When soil fertility was either medium- to high-fertility, revenue gains were strongly related to spatial variability. This trend was not evident when low-fertility land areas dominated fields. As the size of site-specific management units decreased, amounts and costs of fertilizer increased. This trend was observed as land fertility variability increased. Revenue gains were lowest for uniform application management strategies in medium- to high –fertility fields. The converse is true for this strategy. The authors found that returns from uniform rate applications on predominantly low-fertility fields were superior to VRT since the entire area it applies large amounts of fertilizer to all areas, as opposed to VRT. On the other hand, where there is a mosaic of soil fertility, returns from VRT are greater than uniform application strategies. Multiple-rate VRT suffers losses only when fields were mainly high-fertility with little variability. VRT identifies specific high productivity areas of a field that can be targeted for higher fertilizer rates, thus maximizing the productivity of that area. Returns from uniform rate application were generally greater than VRT or split-application VRT. The authors expected that returns from uniform rate treatments would be greater on more homogenous fields than either VRT treatment, they were surprised that returns were greater for uniform rate treatments for variably low-fertility fields. For all systems simulated, return levels increased as field area increased because fixed costs are distributed over more hectares. Environmental benefits accrued from VRT decrease as marginal soil fertility increases because of decreasing marginal productivity of total N related to the assumed fertilizer response function. (Return to Table 9.)

Crop: corn

Technology: VRTN
Region: Ontario

Watkins, Bradley K., Yao-chi Lu, and Wen-yaun Huang. 1998. Economic and environmental feasibility of variable rate nitrogen fertilizer application with carry-over effects. Journal of Agricultural and Resource Economics, 23(2): 401-426. (Return to REFERENCES.)

Objective: An EPIC crop growth and a dynamic optimization model were used to study the environmental impacts and profitability of variable rate versus single-rate, uniform N application in potato production over the long-term, including carry-over effects.

Methods: Yields from a 63 ha potato operation were quantified. Potato crops were rotated with wheat and barley. The authors classified the total yield into four yield groups. A dynamic optimization model was used to resolve steady-state N fertilizer levels for each yield group and the field. Sixteen N application rates were specified for potato, wheat, and barley. Four application methods were evaluated (variable rate and fixed rate, both subdivided into pre-plant applications application during growth). Grid sampling was used to determine soil properties. The model simulated rotation/production of these three crops for 30 years. Two N application methods were tested: pre-planting applications and split applications. Potato yields and nitrate-nitrogen carry-over concentrations were collected then incorporated into the model.

Results/Conclusion: The total costs of variable rate fertilization ($40.74/ha) outweighed the benefits gained from keeping optimal plant-N requirements in each yield group. Conventional, single-rate N application methods ($16.92/ha) were more efficient in this context. During the potato rotation, the split N-application for both techniques (VRT and conventional) produced slight returns above the preplant application strategy. N losses were not different between conventional and variable rate applications implying that neither method was superior with regards to environmental benefits. However, N losses to the environment were less under the split application protocol than preplant applications. The authors raise several valid points about their findings. The model was programmed to simulated yields for seed potato, and not N losses. Secondly, only N availability and soil characteristics were used to explain yield variability, while many other factors contribute to yield. Thirdly, a single field map representing one year was used to estimate soil characteristics throughout the entire simulation. The authors recommend using four to five years of field map data. Lastly, only one input was varied during the simulation: N application. Profitability of alternative application management methods could be more accurate if additional variables (water, seeds, and pesticides) were added to the model. (RETURN TO INTRODUCTION.)

Crop: potato
Technology: VRTN, modeling
Region: Idaho, any

Watkins, Hal. 1999. Additional analysis tools based on yield data. Precision agriculture: proceedings of the 4th international conference, July 19-22, p. 1693, ASA/CSSA/SSSA. (Return to REFERENCES.)

Objective: To offer producers a useful analysis tool to evaluate farms or field profitability using yield data.

Methods: Variables such as cash rent, input costs, cost-effectiveness of tillage practices, and returns from variable rate technologies are included in an algebraic formula designed to complement GIS data.

Results/Conclusion: Yield was represented as revenue per acre and profitability by acre. The author concludes that better managers would use this type of information to continue farm expansion (by rent or lease), or to re-negotiate other farm loans.

Crop: na
Technology: record keeping, computer use
Region: na

Weiss, Michael D. 1996. Precision farming and spatial economic analysis: research challenges and opportunities. American Journal of Agricultural Economics, 78: 1275-1280. (Return to REFERENCES.)

Objective: The author asks under what conditions is profit the net result of precision agriculture activities, how does the environment benefit from these practices, what level and detail of spatial variability is needed to conduct unsubstantiated reports analyses.

Methods: The author uses personal experience to and supporting sources to define the role of spatial economics in the analysis of the economic feasibility of precision agriculture.

Results/Conclusion: Traditional time-series analyses are not sufficient for analyzing the economic feasibility of precision agriculture. Instead, analytical tools such as spatial econometric and spatial statistics are needed since factors such as surface (field variability), time, and yield (production/area/time) must be assigned costs. Costs of fertilizer soil testing and application are influenced as the aforementioned factors vary over time and space. The producer practicing precision agriculture is challenged to estimate initially unknown spatial variability, deciding where and when fertilizer should be applied to variable regions, and at which amounts. Identifying variation in soil fertility is largely agronomic, while determining fertilizer application rates is economic.

Crop: any
Technology: precision agriculture, general
Region: any

Wibawa, Winny D., Duduzile L. Dludlu, Larry J. Swenson, David G. Hopkins, and William C. Dahnke. 1993. Variable fertilizer application based on yield goal, soil fertility, and soil map unit. Journal of Production Agriculture, 6(2): 255-261. (Return to REFERENCES.)

Objective: The authors conducted three variable rate application experiments with wheat over three seasons. The objectives were to determine whether crop yields and net returns would be augmented using fertilizer recommendations based on soil fertility, yield goal, and soil maps. A conventional, uniform application with a fertilizer rate determined by averaging soil test results across the field that was used as a control.

Methods: A field composed of seven soil types was tested for soil fertility. Nitrogen, phosphorous, and potassium test results were used to produce a soil fertility map. Samples were taken at five depths, at the surface to 48-in at 6-in intervals. Grid sizes were 2500 ft^2. Soil sampling costs were based on a local dealership custom fee of $30.00 for 20 core samples per depth. The average field size in North Dakota is 60-acres. The authors reasoned soil samples for fields this size would cost $0.50 to $1.50/core when spread out. Treatments for one season included (1) no nitrogen application; (2) nitrogen and P applications based on averaged soil test results and a yield goal of 80 bu/acre (conventional); (3) variable application of nitrogen and P rates based on grid sample results and a 80 bu/acre yield goal, and (4) nitrogen and P rates based on grid sampling and a yield goal determined for each fertility zone. Treatments applied other seasons included the above, yet slightly modified using larger grid sizes (150 x 150 ft) and lower yield goals (50bu/acre). A partial budget was used to evaluate profitability of treatments.

Results/Conclusion: In 1989 and 1990, Treatment 2 produced the highest net returns of $73.14/acre, 80 bu/acre and $156.42/acre, 60 bu/acre, respectively. In 1991, a treatment including soil test information and soil types, and a fertilization rate based on a 50 bu/acre yield goal produced the largest net return of $114.16/acre. The authors conclude that grid soil sampling provides a good estimate of field fertility variability, but resulted in a net loss because of costs. An "information approach" - using soil test, averaging these results, and making fertilizer rate recommendations based on this average, had the best results. (Return to Table 9.)

Crop: wheat
Technology: VRT, grid sampling
Region: North Dakota

Wollenhaupt, N.C., and D.D. Buchholz. 1993. Profitability of farming by soils. *In* Site-specific management for agricultural systems, p. 199-211, ASA/CSSA/SSSA/, Madison, WI. (Return to REFERENCES.)

Objective: The authors summarize the results of four field trials that investigated the marginal returns of variable rate application.

Methods: The variable costs associated with grid and soil sampling tests, map making, fertilizer costs and application, data management costs, and labor costs are given. Two soil analysis techniques are compared: soil potential and nutrient grid techniques. Information each technique provided was used to generate soil maps. From these maps, fertilizer recommendation rates were made. Crop yields were compared between treatments, along with a yield return minus cost analysis.

Results/Conclusion: Site-specific soil management techniques were not profitable compared to conventional soil fertility management techniques. Special application equipment, additional soil sampling and analysis, data management and map making incurred higher costs of the site-specific management strategy. Variable rate applications did not decrease yields when compared to conventional application strategies. The study raises the question as to what appropriate sample spacings are optimal for yield and profit.

Crop: wheat
Technology: VRT
Region: Montana, Minnesota, Missouri

Wollenhaupt, Nyle, C., Richard P. Wiolkowski, and Harold F. Reetz. 1993. Variable-rate fertilizer application: update and economics. Unpublished document, University of Wisconsin-Madison Potash and Phosphate Institute, Monticello, Ill. (Return to REFERENCES.)

Objective: To summarize findings of an on-going study examining soil-testing strategies, grid sampling methods, and soil fertility zone contour mapping, and the economic feasibility of making variable rate fertilizer application recommendation using these techniques.

Methods: Two corn production fields were used as study sites. Grid-point and grid-cell sampling methods strategies were used to obtain soil nutrient information. Five core samples were collected in each grid. Grid sizes tested in the grid-point method were 106 x 106, 212 x 212, or 318 x 318-ft. Grid sizes in the grid-cell sizes were 318 x 318-ft. In this treatment, soil sample results were either averaged using five sample points (treatment A), or considered representative for that grid using 72 sample points (treatment B). Samples were taken at the intersection of each grid for the former method. In the grid-cell method, samples were taken along the diagonal of each grid. Four mapping techniques were compared: (1) inverse distance weighting, (2) fitting regression functions to field data followed by inverse distance weighting, (3) point kriging, and (4) block kriging. The authors assumed a $2.50 bu/acre corn price and phosphorous and potassium fertilizer prices to be $0.25 and $0.12/lb, respectively. Fertilizer rate recommendations were made using the results of each method. Fertilizer was applied according to each recommendation.

Results/Conclusion: Comparing results between both field, the only treatment generating positive net returns was the grid-point sampling method with a 318 x 318-ft spacing. Results from the other methods between field were mixed. The authors conclude that although these methods certainly provide useful information about soil fertility zones, single-rate application methods are still more cost-effective than variable rate techniques. However, the information provided by soil testing gives the producer a more exact idea how much fertilizer to apply to a specific field than to rather rely on general extension information. (Return to Table 9.)

Crop: corn
Technology: VRT, grid sampling
Region: Wisconsin

Wollenhaupt, N.C., and R.P. Wolkowski. 1994. Grid soil sampling for precision and profit. Unpublished manuscript. Department of Soil Science, University of Wisconsin, Madison, WI. Modified from a paper prepared for the 24th North Central Extension-Industry Soil Fertility Workshop, St Louis, MO, October 26-27, 1994. (Return to REFERENCES.)

Objective: To provide a detailed methodology of grid sampling, and to determine economically optimal grid dimensions for site-specific fertilizer recommendations. A detailed list of procedural costs is included.

Methods: The authors provide a step-by-step list how soil testing by grid sampling is accomplished. Hypothetical grids of varying dimensions were chosen. Then, a breakdown of the associated costs (labor, data analysis, and laboratory tests) by acre is outlined. Using yield and input/output cost data from five different farms, the authors produce a partial budget. To estimate yield, response functions were adjusted to real crop and fertilizer prices. Simulated results were used in the partial budget analysis.

Results/Conclusion: Sampling density influenced mapping accuracy. The degree of precision and soil sampling costs has to be considered when determining sampling density. In three fields, dense soil sampling revealed that although there was much variability, readings were such that no fertilizer was needed since the field soil was high quality. Soil and pH tests were low for the remaining two fields. Problem areas required further testing to accurately pinpoint fertility-poor zones. Economic returns were mixed. The authors conclude that field history should be a guide as to whether or not grid sampling is needed. If indicators suggest that grid sampling might remedy fertility-poor soils, then again field history should be consulted. Soil sampling may require more than one trip to a field in order to fine-tune recommendations.

Crop: corn

Technology: grid sampling, VRT
Region: Wisconsin

Yadav, Satya N. 1997. Dynamic optimization of nitrogen use when groundwater contamination is internalized at the standard in the long run. American Journal of Agricultural Economics, 79: 931-945. (Return to REFERENCES.)

Objective: The objective of this study was to determine optimal N input levels for continuous corn production, keeping N loading into groundwater less than 10 ppm. Experimental data was used to produce policy relevant information after it served as the raw material for a dynamic optimization model. The objective of the model was to stabilize nitrogen load in the groundwater over time. The model included a social benefit function. Results were compared with extant policy regulating nitrogen contamination rates in groundwater.

Methods: The author combines three years of production data from three different sites and different combinations of treatments, including use of inorganic or organic N, N application timing, application method, and tillage practices. The experiment was a randomized block design with a total of 608 data points. Soil-water samples from each site were collected from a depth of eight feet. Samples from groundwater sources were not available. Three different dynamic optimization models were borrowed then adapted to make the model used in this report. The resulting model included a social benefit function to measure what effects an increase or decrease in nitrogen use would have on society (as externalities) and private profit (the farm firm).

Results/Conclusion: Years and treatments varied significantly across sites. Within sites, there no differences between treatments were observed. From the model results, farmers in this region are using substantially more N fertilizer than recommended by extension agents, and more than is necessary to maximize profits. Furthermore, the model indicates that it is more prudent to apply nitrogen based on specific site needs, than one general application rate for the entire region (based on current extension recommendations). In the three study sites nitrogen application rates exceeded profit-maximizing levels. In addition, recognizing carryover effects from N applications from previous years, the author foresees N rate recommendations decreasing. It follows that farmers could lower production costs, and the propensity to contaminate groundwater sources with N fertilizers would diminish.

Crop: corn
Technology: VRTN
Region: Minnesota

Yule, I.J., P.J. Cain, E.J. Evans, and C. Venus. 1995. A spatial inventory approach to farm planning. Computers and electronics in agriculture, 14: 151-161. (Return to REFERENCES.)

Objective: The authors provide a synopsis of the components of precision agriculture. A brief description of each is provided. A system to meet the requirements necessary for planning precision agriculture activities, along with financial management strategies is provided. The authors offer a partial budget covering barley, and variable rate fertilizer application.

Methods: System requirements of precision agriculture are listed then elaborated. The authors mention the use of yield and soil maps, and data pertaining to annual weed distribution, topography, hydrology, soil-sampling methods, and data acquisition and storage. A cursory unsubstantiated reports analysis is provided as an example of determining the profitability of these technologies. Using an average annual application rate of 160-kg N/ha with a cost of 30 pence/kg, it costs £48.00/ha to grow barley. Barley market price was assumed to be £100.00/tonne. A yield function is used to determine the economic feasibility of variably applied nitrogen. An optimum grain to nitrogen response was assumed to be a ratio of 3:1.

Results/Conclusion: The authors suggest that site-specific management should permit the economically optimal application to specific management zones in a field, as opposed to uniform blanket application methods. It follows that the smaller the management unit, the greater chance an optimal fertilizer saturation point will be achieved. The effect variable rate application has on profitability depends upon the degree of spatial fertility variability within the field in comparison to returns form conventional, uniform application rates. The authors assume a 6% interest rate with a machinery amortization period of 8 years. With annual returns of £11.00/ha using VRT, an additional £68.00 of capital costs could be supported. The authors estimate a break-even investment level of £13,600.00 on 200-ha. Including other costs such as GPS-modified equipment, variable rate spreaders, and data management systems at package rate of £20,000.00; a producer would have to farm a minimum of 295-ha to make VRT a profitable venture.

Crop: barley
Technology: VRT
Region: England
