# Risk Management Potential of Precision Farming Technologies

## J. Lowenberg-DeBoer

### ABSTRACT

Initial ideas on risk management uses of precision agricultural technology focused on site-specific treatment of problem areas to reduce the probability of low yields and returns. Recent discussions deal with sensor and remote-sensing information to improve marketing and "as applied maps" as trace-back mechanisms to manage liability. A theoretical model is presented that suggests that there are plausible circumstances under which precision farming can reduce temporal yield variability. Empirical evidence from an on-farm trial of site-specific P&K management in the Eastern Cornbelt supports the hypothesis that precision farming can have risk-reducing benefits.

**Key Words:** food safety, GIS, GPS, crop insurance, marketing, precision farming, site specific management, risk.

With the reduction in government price supports and the apparent increase in weather and climate variability, U.S. producers are increasingly concerned about risk management. It has been hypothesized that precision agriculture technologies such as Global Positioning Systems (GPS), Geographic Information Systems (GIS), and variable rate technologies (VRT) may be useful in helping to manage risks (Lowenberg-DeBoer and Swinton). The risk-management hypothesis is based on the concept that precision technologies provide producers with more and better information and increased control of crop growing conditions. This paper will explore the potential of precision farming technology in managing production risk.

Precision agriculture technology is more than GPS. Broadly it is information technology applied to agriculture. Lowenberg-De-

Boer and Boehlje define it as "electronic monitoring and control applied to agriculture, including site specific application of inputs, timing of operations and monitoring of crops and employees (p. 923)." It should be noted that while this paper focuses on use of precision farming for agronomic crops, many of the same arguments could be applied to livestock, horticultural crops, or forestry.

For this paper, *risk* is defined in terms of the Expected Utility Hypothesis with special attention to downside risk (Hardaker, Huirne, and Anderson). Most people do not object to upside variation (e.g. higher yields, higher output prices, higher profits), but it is the downside that worries them. Variance is often a useful statistic to summarize variability of a process and to use in deriving analytical results, but it does not provide a clear perspective on the downside risk problem. Hence, in the empirical portion this paper will make use of stochastic dominance concepts to characterize potential risk advantages of precision-farming technology.

James Lowenberg-DeBoer is professor, Department of Agricultural Economics, Purdue University, West Lafayette, Indiana.
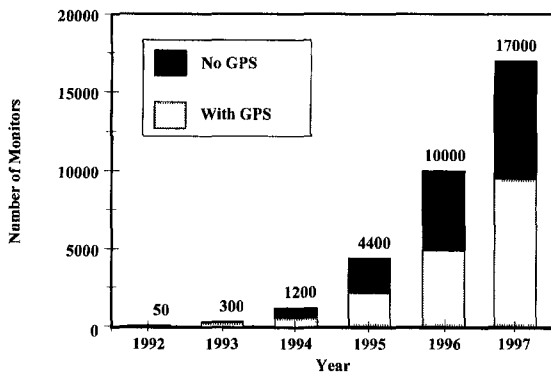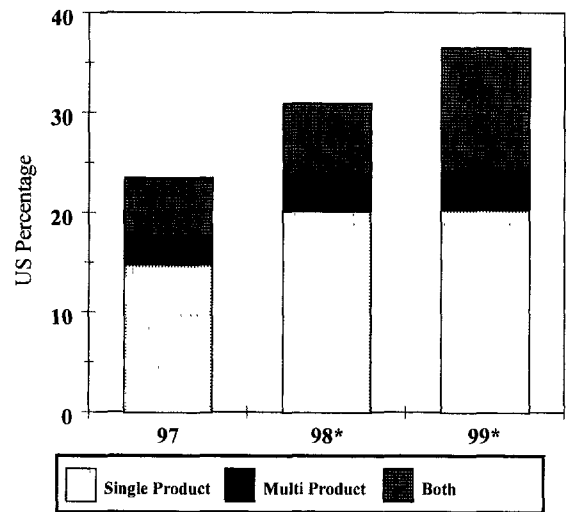
Source: Mangold, 1997

**Figure 1.** Number of combine yield monitors in use in North America with and without GPS



Source: Akridge and Whipker, 1997.
* 1998 & 1999 are based on planned service offering.

**Figure 2.** Percentage of U.S. farm retailers offering controller driven variable rate application services

The organization of the paper is as follows. First, the current status of adoption of precision technology will be summarized. Second, the paper will outline risk management uses of these technologies that are being discussed by precision farming innovators and researchers. Third, it will develop some theoretical reasons for hypothesizing risk reductions with site-specific information and input application. Fourth, the paper will summarize on-farm trial results from the eastern Cornbelt that support the hypothesis that precision farming can reduce production risk. Finally, the paper will close with some suggestions for further research.

## Current Status

Since 1992, precision farming has attracted enormous media attention from the farm press and beyond. Actual investment in precision farming has been promising in some areas, but considerably more modest than the media hype would suggest.

The "killer application" of GPS-based information technology for agriculture has been combine yield monitors. Most previous computer technology applied to agriculture was for things that most farmers found dull and distasteful (e.g., accounting, tax preparation, payrolls). The monitors provide information on something that farmers are passionately interested in—crop yields.

From field testing of a few units in 1992, the technology has grown rapidly (Figure 1). During the 1997 harvest, yield monitors were installed on roughly three percent of all combines (Mangold, Statistics Canada, USDA). Because monitors tend to be on larger, newer machines, it is estimated that yield monitors were used on roughly eight percent of grain and oilseed acreage in North America in 1997. The original devices were for grains and oilseeds, but yield monitors are now being developed for a wide range of other crops. For the 1998 harvest roughly 25,000 yield monitors were in use in the U.S. and Canada.

The other high-profile GPS technology in agriculture has been grid soil sampling and variable rate application (VRA). The availability of grid soil sampling and variable rate fertilizer application has spread rapidly. In 1996, 29 percent of farm retail dealers nationwide offered some GPS-based grid soil sampling (Akridge and Whipker, 1996). In 1997, 33 percent offered this service and by 1999, 43 percent expect to offer it (Akridge and Whipker, 1997).

Controller-driven variable-rate application has seen similar growth (Figure 2). In 1996,

only 13 percent of fertilizer dealers offered controller-driven variable-rate application. In 1997, that estimate was 24 percent. By 1999, the percentage is expected to be 37 percent.

From 1997 to 1998 growth was especially strong in the relatively low-investment single-product spreaders. This growth was often achieved by retrofitting existing equipment. The expected growth in the 1998 to 1999 period is in retailers offering both single and multiproduct variable-rate spreading by making the investment in purpose built multiproduct machines.

For some higher value specialty crops, like sugar beets, use of variable-rate spreading is quite high. Grower surveys indicate that in 1996 about 25 percent of the beet acres in the Red River Valley of North Dakota and Minnesota were grid soil sampled and had nitrogen applied at a variable rate (Cattanach). In 1997 variable-rate application was estimated to be in the range of 27 percent to 30 percent of acreage. The upward trend is expected to continue into 1998.

Many producers of lower value bulk commodities (corn, soybeans, and wheat) are fascinated by the idea of site-specific management of soil fertility. It is an intuitively appealing concept, but the producers have been plagued by continued questions about the profitability of the practice (Lowenberg-DeBoer and Swinton). The response of many growers has been to enroll part of their acreage in one of the site-specific soil management programs offered by fertilizer retailers. For many farmers this is a low cost way to learn about precision farming, without long-term investment in equipment.

The adoption of variable rate planting, variable-rate pesticide application, remote sensing, vehicle guidance systems, and other GPS application is more scattered and is not well documented.

Studies of adoption patterns of precision-farming technology suggest that grain yield monitors are showing rapid adoption in the classic S-curve time path because they can be operated as a stand-alone technology to provide information that increases short-run profitability (Lowenberg-DeBoer, 1998a). Other precision-farming applications may have more irregular adoption patterns similar to that of motorized mechanization as producers and agribusiness search for profitable uses, as integrated systems for site-specific management of many inputs are developed, and as support services and institutions grow.

**Increased Risk with Precision Farming**

Like many agricultural innovations, precision farming may increase some types of risk. It potentially increases yields and returns, but does not eliminate the possibility of crop failure, so variability may be increased. Up-front payments for soil sampling, VRT application of inputs and other services may increase losses in a bad crop season. Even though the investment required for precision farming technology is modest compared to the total capital required for a commercial agricultural operation, investment in precision farming may increase financial risk.

Precision farming also increases human and technological risk. More than most previous new technology in agriculture, the profitability of precision farming depends on human capital. Someone must have the skill to operate the equipment and interpret the data collected. That someone may be the producer, a consultant, or an employee of the local agricultural input supplier. On multi-person farming operations, often one of the partners will specialize in dealing with precision farming. This leaves farming operations vulnerable when that person is no longer available. Someone else may know how to operate the equipment, but interpretation of precision data often requires site-specific knowledge that is only built up with experience.

Similarly, users of precision technology also face technological risk, primarily in the form of obsolescence. Precision-farming technology is young and it is changing very rapidly. Almost every week brings a new gadget or software innovation. A producer may buy something only to find that a month later it has been made obsolete. Even if producers still wish to use that now obsolete technology because it does everything that they originally

asked, it may no longer be supported by the company which has gone out of business, been merged, or has decided that the product is no longer worth supporting.

## Precision Farming and Risk Management

Some of the earliest discussion of precision farming and risk management focused on temporal variability in yields and net returns from season to season (Lowenberg-DeBoer and Swinton). The focus was on creating a more spatially homogenous cropping environment and thereby reducing the number of problem areas which pull down returns in some seasons. Essentially, the hope was to reduce the probability in the lower tail of yield and return distributions across seasons. Some theoretical arguments and empirical evidence on this are presented in subsequent sections.

It should be noted that while spatial variability of yields and returns can present an important production problem, and while it may be an aesthetic issue for some producers and landlords, it is not risk in the usual sense. In most cases the producer is interested in the overall profits for the operation, not whether that result was produced uniformly over his or her fields.

If it could be shown that precision farming could reduce yield and return variability, crop insurance companies should be interested. They might be willing to provide lower insurance rates for producers with site-specific input and yield records. Currently, crop insurance companies are interested in precision technology, but not as it affects actuarial matters or premiums. Crop insurance companies are not offering discounts to precision farmers. Yield monitor data can not be used as evidence of production. Scale tickets and bin measurements are still required.

Some companies and insurance agencies are using GPS technology to improve field area measurement. GPS is particularly useful for irregularly shaped fields. Others see precision farming services as another set of products that they can offer their clients. The recent creation of Geo AgPLUS LLC by IGF Insurance and Glenn Bros., a consulting firm

in Standford, Illinois, fits into this pattern. Geo AgPLUS offers soil sampling and mapping services.

Like many farm input suppliers, some insurance companies and agencies use precision-farming services as a marketing tool. Some offer to map fields with GPS for free to retain current clients and attract new ones. This gives the company a better acreage estimate and the producers field boundary maps which can serve as the foundation for their crop GIS. Field boundary maps may seem like a small item, but input suppliers charge an average of $3.32/a or $30 to $50/hr for field mapping (Akridge and Whipker, 1998).

As the perspective on potential uses for precision technology broadened to include marketing, so did thinking on risk management potential to include the following views:

- Sensors and remote sensing data might provide early yield estimates to help producers in marketing. In explaining a reluctance to contract or hedge, producers often say that they do not feel comfortable selling what they may not have. If crop sensors in fields, aerial photographs, or satellite images could provide better information on the growing crop, this may improve their yield estimates and confidence in early marketing. There have been reports in the farm press of producers using yield monitor information to gauge production and cash in on early harvest cash market premiums while still meeting contractual obligations (Taylor).
- Precision technology pushes agriculture closer to "producing to specification" and hence may make contracting easier. If producers have more control over inputs and output quality, processors may be more willing to enter into contracts that could stabilize returns.
- "As-applied maps" can provide an important trace back mechanism that could reduce insurance premiums and liability claims for input suppliers, producers, and processors. The maps could serve as evidence of proper use in food safety and environmental damage cases. In cases of misapplication, the

maps would serve to limit damage by pin-pointing the source of the problem.

## Theoretical Framework

While the idea of reducing temporal variability of yields and returns by site-specific management to reduce the number of low-yield problem areas seems intuitive, identifying a model which would lead to this result is less obvious. Expected returns to precision farming can often be analyzed with straightforward application of whole-field production economics models to site-specific data (e.g. Lowenberg-DeBoer and Boehlje). Similar adaptations for risk analysis often result in higher intertemporal yield and return variance for site-specific management because in some seasons overall yields are higher, while crop failures are still possible.

This section is an attempt to develop a simple site-specific model in which precision technology could reduce yield variability. It is not a general framework linking spatial variability and intertemporal risk, but a first step which shows that it is possible to outline a plausible mechanism in which site-specific management can reduce intertemporal variability at the field level. It should be noted that initial exploration with several crop response functions suggests that results are very dependent on the function used.

To simplify the presentation the focus is on yield risk as the most likely link between spatial variability and intertemporal net return variability. Input prices are usually known before planting. Variability of output prices has no obvious link to the spatial variability of the crop production environment or farm level input use. It is assumed that output quality is spatially and temporally homogeneous.

Assume a quadratic crop production function with two inputs, one controlled by the producer and the other a stochastic weather index:

$$(1) \quad Y_{ij} = a + b*(X_{ij} + Z_i) + c*(X_{ij} + Z_i)^2$$
$$+ \gamma R_j + \alpha R_j^2 + \theta*(X_{ij} + Z_{ij})*R_j$$

where $Y_{ij}$ is crop yield on site i in year j, $X_{ij}$ is producer input on site i in year j, $Z_{ij}$ is input in the soil on site "i", $R_j$ is stochastic weather index for year j, same for all sites, but differs from year to year, and a, b, c, $\gamma$, $\alpha$, $\theta$ = production coefficients chosen such that an interior optimum occurs for the producer controlled input with average weather: b > 0, c < 0, (b + $\theta*R_j$) > 0 and a higher weather index always produces higher yields: $\gamma > 0$, $\alpha > 0$, $\theta > 0$.

It is assumed that input X is consumed or lost each season. There is no carryover. To simplify matters it is assumed that Z is a permanent soil characteristic. Each year the level $Z_i$ is available. To make this more concrete it may be useful to think of X as applied nitrogen and Z as nitrogen produced in the soil by mineralization of organic matter. In a more complex model with carryover, the soil characteristic could vary from year to year and would need a j subscript.

The model uses two sites and two years as the minimum needed for a discussion of spatial and temporal variability. For the soil, it is assumed that the two management zones are of equal size, one with a high $Z_H$ and the other with a low $Z_L$.

The annual mean yield would be:

$$(2) \quad \bar{Y}_j = (Y_{Hj} + Y_{Lj})/2$$

The intertemporal mean for a two-year period would be:

$$(3) \quad \bar{\bar{Y}} = (Y_{H1} + Y_{L1} + Y_{H2} + Y_{L2})/4$$

The intertemporal variance for the field is:

$$(4) \quad \text{var}(\bar{Y}) = \sum_{j=1}^{2} (\bar{Y}_j - \bar{\bar{Y}})^2/2$$

Substituting equations 1, 2, and 3 into 4, assuming that the input strategy is the same from year to year ($X_{H1} = X_{H2}$, $X_{L1} = X_{L2}$) and simplifying produces:

(5)   $\text{var}(\bar{Y})$

$$= [(\gamma R_1 + \alpha R_1^2 + \theta*(X_{H1} + Z_H)*R_1)$$

$$+ (\gamma R_1 + \alpha R_1^2 + \theta*(X_{L1} + Z_L)*R_1)$$

$$- (\gamma R_2 + \alpha R_2^2 + \theta*(X_{H2} + Z_H)*R_2)$$

$$- (\gamma R_2 + \alpha R_2^2 + \theta*(X_{L2} + Z_L)*R_2)]^2/32$$

$$+ [(\gamma R_2 + \alpha R_2^2 + \theta*(X_{H2} + Z_H)*R_2)$$

$$+ (\gamma R_2 + \alpha R_2^2 + \theta*(X_{L2} + Z_L)*R_2)$$

$$- (\gamma R_1 + \alpha R_1^2 + \theta*(X_{H1} + Z_H)*R_1)$$

$$- (\gamma R_1 + \alpha R_1^2 + \theta*(X_{L1} + Z_L)*R_1)]^2$$

$$\div 32$$

All the terms without the stochastic weather index $(R_j)$ are the same from year to year and cancel out the variance expression. To simplify it should be noted that the term inside of the second set of square brackets is exactly the negative of the term inside the first set of square brackets and the square has the same value regardless of sign. Factoring yields terms in $(R_1 - R_2)$ and $(R_1^2 - R_2^2)$.

(6)   $\text{var}(\bar{Y}) = [\{\gamma + \theta*(\bar{X} + \bar{Z})\}*(R_1 - R_2)$

$$+ \alpha*(R_1^2 - R_2^2)]^2/4$$

where: $\bar{X} = (X_{H1} + X_{L1})/2 = (X_{H2} + X_{L2})/2$ is average X input. $\bar{Z} = (Z_H + Z_L)/2$ is average soil characteristic. Noting that $(R_1^2 - R_2^2) = (R_1 - R_2)(R_1 + R_2)$ this can be simplified further to:

(7)   $\text{var}(\bar{Y}) = [\{\gamma + \theta*(\bar{X} + \bar{Z}) + \alpha*2*\bar{R}\}$

$$\times (R_1 - R_2)]^2/4$$

$$= [\{\gamma + \theta*(X + Z) + \alpha*2*\bar{R}\}^2$$

$$\times (R_1 - R_2)^2]/4$$

where: $\bar{R} = (R_1 + R_2)/2$ is average weather index. Taking the first derivative of the variance with respect to the average input $(\bar{X})$:

(8)   $\text{d var}(\bar{Y})/d\bar{X}$

$$= \theta[\{\gamma + \theta*(\bar{X} + \bar{Z}) + \alpha*2*\bar{R}\}$$

$$\times (R_1 - R_2)^2]/2$$

The sign of the change depends on the inter-action term $(\theta)$. If the interaction term is positive so that better weather and higher inputs combine to create higher yields, the change in variance for a increase in average input level is unambiguously positive. If a producer can cut average input use by applying input only where it is needed and cutting back on areas where soil levels are already high, the average input level might be reduced and the whole field intertemporal variance of yield decreased.

## Empirical Evidence

The search for evidence that precision farming can reduce yield and return risk is just beginning. The only empirical study that specifically address this question comes from a farmer managed on-farm-trial of site-specific P and K fertilization in the eastern Cornbelt (Lowenberg-DeBoer and Aghib). This study was originally designed to determine average returns to variable rate technology (VRT) P and K. It was not designed to test the theoretical model in the preceding section, but it does provide some data relevant to the questions that motivated the model.

The study involved six farmers, all clients of DeKalb-Agra, an input supply and grain marketing cooperative based in Waterloo, Indiana. The project started in 1993 with three farms. In 1994 three additional farmers were included and one of the original group chose to drop out. One farmer had two fields in the trials in 1994. In 1995, three farmers chose to participate. A total of 12 yield observations are available for each treatment during the 1993–95 period. Farms were located in Northeastern Indiana, Northwestern Ohio, and Southern Michigan. All participating farms had soil testing and fertilizer spreading done on a custom basis by DeKalb-Agra. Data collected include yield, field size, type, and quantity of fertilizer applied, as well as initial soil test levels. Lowenberg-DeBoer et al. (1994) provide a description of the trials and early results.

On each farm a field of about 60 acres was requested. The fields chosen by farmers ranged from 40.7 acres to 87.9 acres, with an

**Table 1.** Factors used to compute cost and returns

| Item | Units | Price |
|---|---|---|
| $P_2O_5$ fertilizer | $/lbs. | $0.22 |
| $K_2O$ fertilizer | $/lbs. | $0.12 |
| Whole field sampling | $/field/yr | $3.26 |
| Grid Sampling (3 acre) | $/a/yr | $0.95 |
| Soil Type Sampling | $/a/yr | $0.95 |
| Mapping and Record Keeping | $/a/yr | $2.95 |
| Conventional WFM Spreading | $/a | $4.00 |
| Single Product Variable Rate Spreading | $/a | $5.50 |
| Two Product Variable Rate Spreading | $/a | $6.75 |
| Corn | $/bu | $2.83 |
| Soybeans | $/bu | $6.36 |
| Wheat | $/bu | $3.69 |
| Other Variable Cost Corn | $/a | $94.98 |
| Other Variable Cost Soybean | $/a | $78.33 |
| Other Variable Cost Wheat | $/a | $32.06 |

average size of 58.6 acres (Table 1). Each field was divided into three approximately equal plots, and treatments were randomly assigned. Plots were not exactly the same size in part because of irregularities in field boundaries. The treatments were:

*Whole Field Management (WFM):* the control—soil testing and fertilizer application on a whole field basis.

*Grid:* soil testing and fertilizer application was on a three-acre grid system.

*Soil Type:* soil testing and fertilizer application according to soil type.

The fields used in the study were soil tested before the first cropping season that the field was in the trials. For the WFM treatment, two composite samples of six to 10 cores were taken and the resulting soil tests averaged to determine fertilizer application rates. For all treatments soil samples were six inches deep in no-till fields and eight inches in conventionally tilled fields. The WFM treatment received a single uniform rate of fertilizer over the entire plot. WFM plot size ranged from 8.6 to 23.7 acres.

In the soil type treatment, each major soil type was identified on digitized soil maps. Composite samples were taken with six to 10 cores in each major soil type, resulting in two to four samples for each plot. The soil type plots ranged in size from 9.6a to 19.7a. Phos-

phorus and $K_2O$ rates were determined separately for each major soil type and applied uniformly on the mapped soil type area.

For grid sampling, cell centers were determined by using a GPS. Six to 10 cores were then taken in a 10-foot radius of the center and mixed for a composite sample. The grid management plots ranged from 17a. to 47a. Phosphorus and $K_2O$ rates were determined for each grid and applied uniformly over the three acres. During this period DeKalb-Agra did not use contoured soil test maps. The soil type and grid treatment fertilizer was applied with GPS-equipped commercial multiproduct variable rate equipment.

All cultural practices other than P and K fertilization were decided by the farmer and were uniform for the entire field. Farmers used either a corn-soybean or a corn-soybean-wheat rotation. DeKalb-Agra fertilizer recommendations generally follow the tri-state recommendations (Vitosh *et al.*, 1995). In some cases farmers decided to make maintenance applications on high soil test areas and to make no application when the recommended amounts were very small.

The treatment yields are averages over all yield monitor observations for a given treatment and were collected using combine-yield monitors, with GPS to identify the position in the field. Yield averages were calculated using

Atlas GIS (Strategic Mapping, Inc., 1993). In 1994 and 1995 the GPS locations were differentially corrected to approximately two meter accuracy. At the time when DeKalb-Agra started using GPS, commercial differential correction was not available in their area; hence they installed their own differential correction base station in late 1993. For the 1993 harvest, differential correction was not available and yield monitor observations were manually associated with treatments, using the uncorrected GPS readings and time stamp. The manual process leaves much to be desired in terms of locational accuracy of individual yield points, but it appears to be adequate for identifying the treatment yields per plot.

To allow a general perspective that integrates results over the crop rotation the analysis concentrates on expected monetary returns. Annual net returns to land, machinery, labor, and management were computed by subtracting P&K related costs by treatment and average variable costs by crop from gross returns on a per-acre basis. In a decision-making perspective, average Indiana input costs and output prices are used to focus on the expected return if these technologies were implemented in the near future and to avoid price variations which are important for marketing, but not particularly relevant to the VRT decision.

Grain prices and production costs are averages for the period 1993–1995 (Table 1). Costs for soil sampling, mapping, fertilizer and spreading are from DeKalb-Agra. VRT fees are not well documented, but they vary widely from dealer to dealer. The DeKalb-Agra fees were in the middle of the price range given by Lowenberg-DeBoer (1998b). Whole field soil sampling costs were annualized over the four-year sampling cycle as suggested by Lowenberg-DeBoer and Swinton, (1997). Because the WFM soil sampling is by field, the cost per acre varies with the size of field. The average annual cost of WFM soil sampling for fields in the trials is $0.18/a/yr. The DeKalb-Agra VRT cost schedule at the time prorated sampling costs over the sampling cycle by charging one third of the cost every year. Fertilizer price was estimated as

the three-year average (Doster *et al.*, 1993, 1994, 1995). Other variable costs were also charged at their three-year averages. They include seed, chemicals, machinery fuel and repair, crop insurance, a $1/a miscellaneous charge, and interest at nine percent on variable charges (Doster *et al.*, 1993, 1994, 1995).

To allow for carryover P and K, the budget calculation charged P and K fertilizer costs up to replacement levels in the year applied. The value of P and K fertilizer exceeding the amount needed to replace nutrient removal was annualized assuming a nine-percent discount rate. The first year that a field was involved in the trial, the P and K fertilizer charge was the lesser of removal or application, plus the annualized amount when application was greater than removal. For fields that were in the trial for multiple years, the second and third year P and K charges include annualized amounts from earlier years.

Distributions of returns were estimated pooling data over years and farms, and thus include both inter-annual and intra-annual variability. This type of pooling is appropriate where sources of risk are not limited to weather, but include spatial differences in rainfall, pests, soil, and farm to farm management variability (Hien *et al.*, 1997). The pooling is specifically appropriate for decisions by extension workers and retail agribusinesses concerned with how successful a new technology might be given variability of weather, soils, management, and other factors in their area.

Because of portfolio effects, farm risk management should be done on a whole farm or whole household basis, including all enterprises and sources of income. The focus of this study is on characterizing risk aspects of a specific set of information technologies. It uses mean-variance and stochastic dominance risk analysis as heuristic tools to characterize the riskiness of these technologies relative to current whole-field management practices. This is done by comparing distributions of field-level average returns.

## On-Farm Trial Results

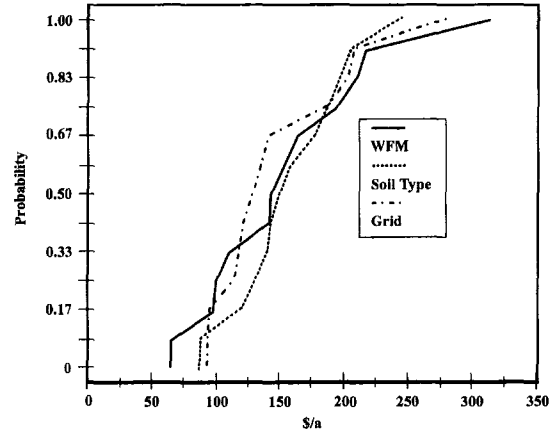Average returns for the soil-type approach are slightly higher than that of WFM (Table 2).

**Table 2.** Descriptive statistics for net return by treatment

|  | Net Return by Treatment | | |
| --- | --- | --- | --- |
|  | Whole Field | Grid | Soil Type |
|  | --------- $/a --------- | | |
| Average | 158.48 | 152.13 | 161.65 |
| Standard Deviation | 67.27 | 56.13 | 42.75 |
| Minimum | 64.91 | 93.14 | 87.60 |
| Maximum | 311.61 | 281.36 | 244.13 |



**Figure 3.** Cumulative distributions of net return for whole field, grid, and soil type management of corn, soybean, and wheat rotations in on farm trials in the eastern Cornbelt from 1993–1995

Average returns for the grid treatment are somewhat lower than that of WFM. Statistically the means were not different at any conventional significance level. This indicated that while soil type management showed a slight advantage over WFM and grid management had a somewhat lower return than the others, this could be due to the fields and the crop seasons in the sample or other random variability. Average fertilizer use did not differ much between treatments. The main effect of site-specific management was to redistribute fertilizer within the field.

In the estimated distributions, the WFM treatment had a consistently higher standard deviation than either the grid or soil type treatments (Table 2). Using the mean-variance decision rule, the soil type treatment dominated both the WFM and the grid management because it had a higher mean and lower variance than the other treatments. Grid management did not dominate WFM with the mean-variance decision rule because it had the lower mean.

In the pairwise comparisons of cumulative probability distributions no alternative dominates by first degree stochastic dominance (FSD). The soil type treatment dominated the WFM by second degree stochastic dominance

(SSD) (Table 3, Figure 3) because the area between the distributions below the crossover at about $180/a is greater than the area above the crossover where the WFM distribution is to the right. For the risk-averse individual, soil type P&K fertilization is preferred because it reduced the probability of low returns without a large reduction in the probability of higher value outcomes.

The grid approach had some advantage over the WFM on low return fields, but had a lower probability of medium and high returns (Figure 3). The WFM had a higher probability of return levels less than $110/a than the grid approach. Graphically, this can be seen because the WFM distribution was mainly to the left for returns less than $110/a. Above the intersection the WFM had a lower probability of producing returns below any given level. For example, the grid approach had an almost two thirds probability of producing returns

**Table 3.** Pairwise risk comparison of net returns per acre for three soil management alternatives

| Comparison | First-Degree Stochastic Dominance | Second-Degree Stochastic Dominance |
| --- | --- | --- |
| Soil Type vs. Whole Field | Non-dominated | Soil Type dominates |
| Soil Type vs. Grid | Non-dominated | Non-dominated |
| Soil Type vs. Grid | Non-dominated | Non-dominated |

less than \$140/a, but WFM had only an approximately 40-percent chance of producing returns below this level. Graphically, the grid approach did not dominate because the area between the distributions above the intersection of the distributions is greater than the corresponding area below the intersection.

The soil type approach had a higher probability of returns below \$80/a than the grid treatment (Figure 3). Consequently, the soil type treatment did not dominate the grid approach even if the soil type distribution is to the right for most of the return range. The slight advantage of the grid treatment above the second intersection at about \$185 did not outweigh the area between about \$80 and \$185 where the soil type distribution was well to the left and thus the grid treatment did not dominate.

Sensitivity testing by dropping observations from each field and year combination in turn and redoing the stochastic dominance comparisons indicates that the results were robust. In no comparison did the WFM approach dominate the SSM treatments. In an additional sensitivity test, observations with wheat were dropped. This did not change SD risk rankings. In the sensitivity testing the SSM advantage in low return situations was maintained regardless of the sample composition, but the higher maximum returns for the WFM appeared to be linked to data from Farm 2 in 1993.

## Conclusions

This study outlined the potential for use of precision agricultural technology for risk management in crop production. Studies show that some aspects of precision agriculture are being rapidly adopted by U.S. farmers. Initial discussions of risk management uses of the technology focused on site-specific treatment of problem areas to reduce the probability of low yields and returns. More recent discussions deal with use of sensor and remote sensing information to improve marketing and "as applied maps" as trace-back mechanisms to manage liability costs. A simple theoretical model is presented that suggests that there are

plausible circumstances under which precision farming can reduce whole-field temporal yield variability. Empirical evidence from a on-farm trial of site-specific P&K management in the Eastern Cornbelt supports the hypothesis that precision farming can have risk benefits. That data suggests that site-specific management can reduce probability in the lower income distribution.

Research in the use of information technology to manage risk in agriculture is just beginning. Additional work is needed to develop a general framework for the link between within-field spatial variability and whole-field temporal variability. Empirical work, especially on-farm trials, is needed to determine the potential for widespread risk management benefits from precision agricultural technology. Use of precision farming technology in marketing is virtually unexplored and may be of far greater importance than modest risk reduction benefits in crop production.

## References

Ackridge, Jay and Linda Whipker, "1996 Precision Agricultural Services: Dealership Survey Results." Center for Agri-Business Staff Paper No. 96-11, June 1996.

Ackridge, Jay and Linda Whipker. "1997 Precision Agricultural Services: Dealership Survey Results." Center for Agri-Business Staff Paper No. 97-10, June 1997.

Akridge, Jay, and Linda Whipker. "Sharper Look at the Leading Edge." *Farm Chemicals,* June 1998, p.12–15.

Cattanach, Allan. Personal Communication, Extension Sugarbeets. North Dakota State University, Fargo, North Dakota, 1998.

Doster, H.D., S.D. Parsons, E.P. Christmas, D.R. Griffin, S.E. Hawkins, and R.L. Nielsen. "1995 Purdue Crop Guide." Purdue University, Cooperative Extension Service, ID-166, 1995.

Doster, H.D., S.D. Parsons, E.P. Christmas, D.R. Griffin, S.E. Hawkins, and R.L. Nielsen. "1994 Purdue Crop Guide." Purdue University, Cooperative Extension Service, ID-166, 1994.

Doster, H.D., S.D. Parsons, E.P. Christmas, D.R. Griffin, D.B. Mengel and R.L. Nielsen. "1993 Purdue Crop Guide." Purdue University, Cooperative Extension Service, ID-166, 1993.

Hardaker, J., Brian Ruud, B.M. Huirne, and Jock B. Anderson. *Coping with Risk in Agriculture.* CAB International, New York, 1997.

Hien, Victor, Daniel Kaboré, Sansan Youl, and J. Lowenberg-DeBoer. "Stochastic Dominance Analysis of On-Farm-Trial Data: The Riskiness of Alternative Phosphate Sources in Burkina Faso." *Agricultural Economics* 15, 3 (January 1997):213–221.

Lowenberg-DeBoer, J. "Adoption Patterns for Precision Agriculture." In *Agricultural Machine Systems,* SP-1383, Society of Automotive Engineers, Warrendale, PA, September 1998.

Lowenberg-DeBoer, J. 1998. "What Price is Right?" *Farm Chemicals* 161, 4 (1998):20–23.

Lowenberg-DeBoer, J. and Anthony Aghib. "Average Returns and Risk Characteristics of Site Specific P&K Management: Eastern Cornbelt On-Farm-Trial Results." *Journal of Production Agriculture* 12, 2 (1999):276–282.

Lowenberg-DeBoer, J. and Michael Boehlje. "Revolution, Evaluation, or Deadend: Economic Perspectives on Precision Agriculture." In *Precision Agriculture, Proceedings of the 3rd International Conference on Precision Agriculture,* P.C. Robert, R.H. Rust and W.E. Larson (eds.), SSSA, Madison, Wisconsin, 1997.

Lowenberg-DeBoer, J. and S.M. Swinton. "Economics of Site Specific Management in Agronomic Crops." In F.J. Pierce and J.D. Sadler, *The State of Site-Specific Management in Agriculture,* ASA-CSSA-SSSA, Madison, Wisconsin, 1997.

Mangold, Grant. "How Many Monitors?" *Agriculture Innovator* 5, 3 (December 1997):2.

Strategic Mapping, Inc. Atlas GIS for Windows, Version 2.0. Santa Clara, California, 1993.

Statistics Canada. 1997 *Canada Yearbook.* Ottawa, Ontario Canada, 1997.

Taylor, Owen. "Yield Monitors are Marketing Tools." *Soybean Digest* (October 1998):6.

United States Department of Agriculture. *Agricultural Statistics.* National Agricultural Statistics Service, Washington, DC, 1997.

Vitosh, M.L., J.W. Johnson, and D.B. Mengel. "Tri-State Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa." Michigan State University, Ohio State University and Purdue University, 1995.