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Crop Production Using Variable Rate Technology for P&K in the United States Midwest: Evaluation of Profitability

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Abstract

This study evaluates profitability of crop production with variable rate technology (VRT) for P&K application relative to profitability of crop production with uniform rate technology (URT) using data from six fields with a corn-soybeans rotation situated in Indiana. The results suggest that crop production using VRT is more profitable than using URT in one of the six fields. In the case of the other five fields profitability of crop production using VRT relative to using URT falls in the range of 85 to 92%. Under the assumption of lower costs for field diagnostic services and variable rate fertilizer application profitability of crop production using VRT increases.

1. Introduction

Many Midwestern fields are not uniformly structured in terms of soil type, quality, or fertility. Fields often have areas with high phosphorus and potassium (P&K) content and areas with low P&K content. Agricultural producers must choose whether to use conventional (uniform) fertilizer application technology or variable rate technology on this type of land. Using uniform technology creates (URT) problems such as decreased yield from under and over use of fertilizer and environmental problems from over use of fertilizer. This over and under use of fertilizer results in economic consequences for the producers, with extra money spent on unnecessary fertilizer and yield penalties.

Variable rate technology (VRT) allows application of a variable amount of fertilizer on each plot of land, depending on the initial content of soil nutrients in the particular plot. Therefore, on the same field, some areas receive lower levels of applied fertilizer or no fertilizer at all, while some areas receive higher levels of applied fertilizer. Choosing between the two fertilizer application technologies (URT and VRT) is a problem for anyone who deals with crop production on land with the above mentioned characteristics. Ultimately, the decision depends on economic benefits and costs.

Several studies have been conducted to assess profitability of using variable rate technology of fertilizer application[1]. In general, conclusions on profitability of variable rate technology are mixed. They depend on the crop under consideration, type of nutrients (N and/or P&K), soil characteristics, and methodology used to assess profitability. A group of results that indicates at least some level of profitability of VRT over the

[1] Surveys of studies evaluating precision fertilizer application are presented in Lowenberg-DeBoer and Boehlje (1996) and Swinton and Lowenberg-DeBoer (1998). A more comprehensive survey of studies that evaluate various components of precision farming, including precision fertilizer application, is presented in Griffin *et al* (2004).

traditional fertilizer application technology do not account for cost of field diagnostic and variable rate fertilizer application in a proper way.

Therefore, these results overestimate the level of profitability. Also, the majority of studies use a partial budget analysis that does not allow to capture all benefits of variable rate technology. In summary, the general conclusion is that VRT is not a profitable strategy.

This study aims to conduct a more critical evaluation of benefits from using VRT. The first objective of this study is to evaluate profitability of crop production with VRT for P&K using a net present value (NPV) optimization approach that incorporates a site-specific response function for a corn-soybean rotation. Profitability of crop production using VRT is evaluated relative to profitability of crop production using URT and information technology (IT) on six fields situated in Indiana. The cost of gathering site-specific information and cost of VRT application are directly incorporated in the models. Compared to a partial budget analysis used in previous studies, modeling crop production process using a site-specific response function and costs of field diagnostic services, including cost of VRT application, allows for a more critical assessment of VRT profitability.

The second objective is to evaluate profitability of crop production using VRT relative to using URT and IT under different scenarios. First, we consider different levels of costs of field diagnostic services and VRT application. The available detailed information on prices for field mapping, soil sampling, agronomic recommendations, and VRT application for a few consecutive years is utilized to simulate an alternative set of results. Second, we consider higher prices for P&K. As VRT technology is expected to reduce the amount of fertilizer applied, under the assumption that fertilizer prices are going to increase, the benefits of using VRT might outweigh the benefits of using URT.

Prices for phosphorus and potassium have increased by 64 and 69 percent, respectively, during the period of 2003-2006 (Table 1). However, prices for field diagnostic services and precision fertilizer application were relatively stable during the same period (Table 2). In addition, prices for some specific services have even declined. Under these trends the profitability of crop production using VRT may be higher than profitability of crop production using URT.

The results of this study may have important implications for decision makers in the area of agribusiness, such as agricultural producers, fertilizer and agricultural input firms' dealers, consultants, and extensions agents. The results may be used by agricultural producers to modify their production strategies and by fertilizer and agricultural input firms' dealers to improve their marketing strategies.

The paper is organized as follows. Section 2 presents a literature review of the studies that evaluated profitability of VRT. Section 3 discusses the methodology. Data are presented in Section 4. The simulation results are discussed in Section 5. Finally, the conclusion of the research is presented.

2. Literature Review

According to Lowenberg-DeBoer and M. Boehlje (1996) "the essence of precision agriculture[2] is obtaining more data on production processes and converting that data into information that can be used to manage and control those processes". The authors emphasize the crucial role of information for decision-making in agriculture and agribusiness today. Information represents one of the significant sources of strategic

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[2] Precision agriculture practices include variable rate of seeding, fertilizer, pesticide and herbicide application, field mapping and soil sampling, and others. For a review of these practices see Griffin *et al* (2004).

competitive advantage. Consequently, information is a source of additional value that can be extracted from the market by a firm that is able to find out necessary information, makes a timely interpretation, and properly uses it in management.

Variable rate technology of fertilizer application is one of the precision agriculture practices. It is a relatively new technology. Adoption of this type of technology is a sequential process consisting of three stages (McBride and Daberkow (2003)). At the first stage producers become aware of the existence of this technology. At the second stage information on soil characteristics is collected and analyzed. This stage usually includes field mapping, soil sampling, and analysis of gathered data. The results of the second stage may recommend either to use variable rate technology for fertilizer application or not to use it. Therefore, the producers who go through the second and the third stages may be considered to be the adopters of variable rate technology for fertilizer application.

In practice, the adoption of variable rate technology for fertilizer application has been going relatively slow. McBride and Daberkow (2003) use data from the USDA 1998 Agricultural Resource Management Survey to analyze factors influencing the adoption of precision technologies by corn and soybean producers. Farmers who are aware of existence of precision farming constitute 59% of the sample. Only 19% of this group adopted one or more of the field diagnostic techniques. Only 9% adopted precision application techniques. On average, relatively young farmers, farmers with education, and farmers managing large farms are more likely to be adopters at each of the three stages. It turns out that important role in the adoption process belongs to crop consultants and input suppliers. The latter often provide field-sampling services, develop recommendations, and perform variable rate application. If a farmer is in contact with any of these agents, the probability of precision agriculture adoption by the farmer increases by approximately

50% in each case relative to all other sources of information about precision practices (extension agents, media sources, other grows, etc.).

There are at least few factors that may explain this slow adoption rate. First, as the results of the above mentioned survey indicate, almost half of the producers who might potentially use variable rate technology are not aware of it. Second, the introduction of this technology requires additional investments. Third, there are various risks involved. Finally, the benefits from using variable rate technology might be lower than the benefits from using uniform rate technology. The latter is supported by previous findings (Lowenberg-DeBoer and Boehlje (1996), Schnitkey *et al* (1996), and Lowenberg-DeBoer and Aghib (1998)).

Lowenberg-DeBoer and Boehlje (1996) present a review of available studies analyzing profitability of variable rate technology. The results of the studies are mixed. They depend on the crop and nutrients under consideration as well as the methodology employed to evaluate profitability of precision farming. The authors conclude that the profitability of precision farming remains elusive at the farm level, and suggest analyzing it in the light of structural changes taking place in agriculture today. Next, we mention two studies assessing profitability of variable rate technology for phosphorus and potassium.

Schnitkey, Hopkins, and Tweeten (1996) evaluate precision fertilizer (P&K) applications using a site-specific crop response function on 18 corn-soybean fields in the Northwest Ohio. The authors evaluate returns from the three alternative fertilizer application strategies: uniform, variable rate, and information strategies. This approach allows distinguishing the returns from information gathering and variable rate application. The authors find that gathering information increases returns by an average of $5.74 per acre per year. Precision fertilizer application will result in additional increase of returns by $3.28 per acre per year. The authors conclude that under the assumptions that the information gathering using grid sampling costs about $1.00 per acre and precision fertilizer application costs about $3.00 per acre[3] both information gathering and precision fertilizer application are feasible. It is pointed out that some fields exhibit low returns. Therefore, precision fertilizer technology would not provide a net profit for all fields.

Lowenberg-DeBoer and Aghib (1998) evaluate returns and risk characteristics of site-specific P&K management in the eastern Corn Belt, using data collected from the farmer managed on-farm trials. Three approaches of fertilizer application were considered: whole field, soil type, and variable rate (site-specific or grid) approach. The authors conclude that the site-specific P&K management approach does not reliably increase returns as stand alone practice in the case of corn, soybean, and wheat production. The average net returns to the soil type approach were $3 per acre higher then those of the whole field management approach. The average net returns to the grid management approach were $6.35 per acre lower than in the case of the whole field management. In addition, these average differences are not statistically significant. The authors conclude that the main effect of the variable rate fertilizer application is to redistribute the nutrient application across the field, rather than to decrease the amount of fertilizer applied.

Precision technology for fertilizer application is likely to be more profitable than uniform rate technology under the following circumstances (pointed out by Swinton and Lowenberg-DeBoer (1998)). The first situation is when fields are characterized by high soil variability. The second situation is when highly fertile homogenous soils have areas with low P&K content. If a precision fertilizer application is used in the latter case to raise (build-up) the nutrient content, then VRT is likely to be more profitable. As noted

[3] The information source cited is Lowenberg-DeBoer and Swinton (1995).

by Brouder and Lowenberg-DeBoer (2000), variable rate application of fertilizer is not likely to be profitable if a field has a relatively uniform structure or the variability in the nutrient content is substantial but the levels of nutrients are in the "high" nutrient availability range (above critical levels).

3. Methodology

The profitability of crop production using variable rate technology (VRT), information technology (IT), and uniform rate technology (URT) for P & K is evaluated using a net present value (NPV) analysis. We optimize (maximize) the net present value, which is the discounted sum of the projected series of the net cash flows of the crop production process using VRT, IT, and URT. In other words, we maximize the discounted profit from crop production using each of the technologies under consideration over a four-year horizon for six fields situated in Indiana. The choice (endogenous) variables are the amount of phosphorus and potassium to be applied to maximize the objective function (NPV) in the case of each field:

$$NPV = \sum_{t=1}^{T} \left(\frac{R_t}{(1+d)^t} - \frac{C_t}{(1+d)^{t-1}} \right) - SSI.$$

The revenue cash flows (R_t) are calculated as the price of the final product (corn or soybeans) multiplied by the amount of output determined using the site-specific response function. The cost cash flows (C_t) are represented by variable and some fixed costs of soybean and corn production, including either the cost of the uniform or variable rate technology for fertilizer application. The initial outlay (*SSI*) is represented by the costs of gathering and analyzing site-specific information (soil sampling, filed mapping, and agronomic recommendations). These costs are incurred in the case of VRT and IT. Finally, d is a discounting factor.

We use a site-specific response function for a corn-soybean rotation (Schnitkey *et al* (1996)). This function is estimated to analyze crop productivity in the Northwestern Ohio, and can be used to analyze crop production in Indiana, as field characteristics are very similar in these two states. The site-specific crop-response function is estimated for four years, and is a nested function of four production functions: corn first year response (the first year of crop rotation), soybeans first year response (the second year of crop rotation), corn second year response (the third year of crop rotation), and soybeans second year response (the fourth year of crop rotation). The carry-over equations for phosphorus and potassium are incorporated in these functions.

The following assumptions correspond to the set up of the optimization problem in this study.

1. Income from crop production is generated by the end of the year. Therefore, the revenue cash flows are discounted starting from the first year.

2. All expenses are incurred at the beginning of each year. Therefore, the cost cash flows are discounted starting from the second year.

3. A custom operator (cooperative, agricultural input firm or fertilizer dealer) provides either uniform or variable rate fertilizer application.

4. Phosphorus and potassium are applied during the first and the third years in crop rotation.

The specific features of an optimization problem in the case of each technology are outlined below (discounting factor is not included for the simplicity of representation).

Variable rate technology

Under the variable rated technology a field is considered to be heterogeneous in terms of P&K content. The latter varies across the field. The amount of P&K applied to one grid is determined independently from the amount of P&K applied to the other grids of the same field. The first step is to find the amount of P&K that maximizes the NPV for each grid. The second step is to calculate the field NPV. It is done by a summation of the NPVs calculated for all grids.

$$NPV_i = \max \sum_{t=1}^{t=T} \left(C(S)_t * F_{ti}(P_{ti}^0, K_{ti}^0, P_{ti}, K_{ti}) - r_{pt} * P_{ti} - r_{kt} * P_{ti} - VRT_{ti} - C_{ti} \right) - SSI,$$

$$NPV_{field;VRT} = \sum_{i=1}^{i=N} NPV_i,$$

where: $C(S)$ is the price of corn or soybeans,

$F_{ti}(P_{ti}^0, K_{ti}^0, P_{ti}, K_{ti})$ is the production function corresponding to year *t* and grid *i*,

P_{ti}^0, K_{ti}^0 are the initial content of P&K at the beginning of year *t* in grid *i*,

P_{ti}, K_{ti} are the amount of P&K to be applied in year *t* to grid *i* to maximize NPV_i,

r_{pt}, r_{kt} are prices of P&K in year *t*, and

VRT_{ti} is the cost of VRT application in year *t* and grid *i*,

N is the number of grids representing the field, and

T is the number of years.

Information technology

Under the information technology, a field is viewed as heterogeneous in terms of P&K content, and homogeneous in terms of the amount of P&K applied. The amount of P&K is applied to the field at the uniform rate which is based on the information about P&K content in all grids. Therefore, in contrast to the VRT case, the amount of fertilizer applied to each grid, which is the same, depends on the information about P&K stocks in all other grids.

$$NPV_{field;IT} = \max \sum_{i=1}^{i=N} \left(\sum_{t=1}^{t=T} C(S)_t * F_{ti}(P_{ti}^0, K_{ti}^0, P_{ti}, K_{ti}) \right) - \sum_{t=1}^{t=T} \left(r_{pt} * P_t + r_{kt} * K_t + URT_t + C_t \right) - SSI,$$

where all notations are as above, and URT_t is the cost of the uniform rate application.

Uniform rate technology

Under uniform rate technology, a field is viewed as homogenous in terms of both information about P&K content and amount of P&K to be applied.

$$NPV_{field;URT} = \max \sum_{t=1}^{t=T} \left(C(S)_t * F_t(P_t^0, K_t^0, P_t, K_t) - r_{pt} * P_t - r_{kt} * P_t - URT_t - C_t \right) - SSI,$$

where all notations are as above.

4. Data

The economic assessment of the three fertilizer application technologies is conducted using data from six fields situated in Indiana. Information on various characteristics of these fields is taken from Karr (1988) and is summarized in Table 3 (field characteristics) and Table 4 (soil characteristics relating to P&K content). The amount of phosphorus and potassium varies significantly across the fields. Although the amount of phosphorus is above the critical level on all fields, the amount of potassium is below the critical level on some of the fields. Therefore, these fields are potential candidates for VRT application. The fields are divided into grids. Information on the initial content of P&K in each grid is available for all fields.

Prices of corn and soybeans and all expenses incurred during the production process are taken from the yearly crop costs and returns guides developed at Purdue University (Miller and Dobbins (2003 and 2004) and Dobbins and Miller (2005 and 2006)). We use information for 2003-2006 years, which is summarized in Table 1.

Information on prices of site-specific services (soil sampling, field mapping, and agronomic recommendations) and prices for fertilizer application (uniform and variable rate fertilizer application) for 2002 year is collected from Whipker and Akridge (2002) and is represented in Table 2.

Discounting rate equal to 5 percent is used in the analysis.

5. Results

In the case of each field four simulations were run to investigate profitability of crop production using VRT, IT, and URT under different assumptions[4]. The differences in the scenarios are due to the level of prices of P&K and prices for soil diagnostic services and variable rate technology application. The average level of prices for diagnostic services and VRT application is used in the first scenario. The second scenario is based on the minimum level of prices for field diagnostic services and VRT application. The third scenario assumes that prices for P&K are approximately 30 percent higher than those used in the first scenario. Finally, the fourth scenario uses the assumptions of the second and the third scenarios (the minimum level of prices for field diagnostic services and higher fertilizer prices).

The first scenario simulation results (Table 5) suggest that only on one (Oxemann) field out of six fields crop production using VRT is more profitable than using URT. The total profit for Oxemann field is $2025.00 in the case of VRT and $1238.00 in the case of URT. Therefore, crop production using VRT is 163.57% more profitable than crop production using URT on this field. In the case of the remaining five fields, the profitability of crop production using VRT is less than the profitability using URT. The

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[4] If simulation results suggest to apply both P and K, then price for variable rate application multiple product service is used in the analysis. If simulation results recommend to apply only one nutrient a year or the amount of the other nutrient is negligible, then price for variable rate application single product is used. As price for uniform rate technology application service is not available for 2002, price for this service from 2004 is used instead.

ratio of the VRT profitability to the URT profitability falls in the range of 84.55% to 91.59% in this case.

Only in the case of Oxemann field the amount of K applied in the VRT case (681 lb/field) is considerably lower than the amount of K applied in the URT case (7117 lb/field). Consequently, the cost of fertilizer is considerably lower. In the case of all other fields, VRT may results either in increase of decrease of fertilizer application. However, these differences are not as significant as in the case of Oxemann field.

An important factor that explains these outcomes is the average initial level of P&K in the soil[5]. The initial content of phosphorus exceeds the critical level on all fields[6]. The initial content of potassium is below the critical level[7] in the case of Hess field and Oxemann field. If the initial content of a nutrient exceeds the critical level, then the URT is likely to provide a more profitable outcome, as no or a small amount of fertilizer is required. If the initial content of a nutrient is below the critical level, and there is variability across the field, then the VRT is likely to provide a more profitable solution than URT. This is what we observe in the case of Oxemann field. Similar to Oxemann field outcome is expected for Hess field, but the results suggest that the VRT is only approximately 89% as profitable as the URT on this field. A possible explanation of this unexpected outcome is different amount of information on the initial P&K stocks for Oxemann and Hess fields. Hess field consists of 63 grids and Oxemann field consists of

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[5] In the case of each field the initial levels of P&K are calculated as the averages of P&K content across all grids representing the fields.

[6] The critical level of phosphorus for corn is approximately 30 lb/acre (Vitosh *et al* (1995)).

[7] The critical level of potassium depends on the soil cation exchange capacity. As the levels of cation exchange capacity are different for all fields, the critical level of potassium for each field is calculated and the results are presented in Table 4. The methodology of calculation of the critical level for potassium is presented in Vitosh *et al* (1995).

100 grids. Therefore, approximately 60 percent more information is provided in the case of Oxemann field relative to Hess field. In the situation of the four other fields differences in profitability of the VRT may be similarly attributed to the differences in the initial amount of P&K in the soil and the amount of information provided. In all these cases the initial content of P&K exceeds the critical levels.

It is important to note that in the situations when the average amount of phosphorus and/or potassium exceeds the critical levels, individual grid P&K content may be below this level. In situations like this crop production with VRT may be as profitable as crop production with URT. For example, in the case of Jones field the average, minimum, and maximum initial contents of K across all grids are 250 lb/a, 98 lb/a, and 535 lb/a, respectively. The average, minimum, and maximum critical values for K calculated for this field are 184 lb/a, 155 lb/a, and 280 lb/ac. Approximately 25 percent of all grids are below the critical level. Similarly, in the case of Clingenpeel field more than 50 percent of girds have K content below the critical level, but the average content is above the critical level. Despite the fact that the average content of K is considerably above the critical level, production with VRT is almost 92% as profitable as production with URT.

An important factor influencing the level of profit in the case of crop production with URT is the initial amount of P&K specified in the model. In this study the average content of P&K across all grids is calculated and used in the model. Given a substantial variability of the nutrients' content across all grids of the fields, changing the initial level of nutrients would change the level of profitability. For example, a decrease in the level of P&K is likely to result in a decrease of the URT profitability. Consequently, using VRT could be more profitable. This highlights the importance of the information used to make decision on the initial levels of nutrients to be used in the analysis. For example, in the case of Clingenpeel field, the mean content of potassium is 216 lb/a, while the minimum and maximum values are 62 and 642. Therefore, any reasonable deviation from the average level specified in the model will decrease or increase the profit from crop production using URT. Consequently, the profitability of crop production using URT relative to the profitability of crop production using VRT will change.

In the second scenario the minimum level of prices for diagnostic services and VRT application are used. The VRT results of Scenario 2 are compared with the URT results of Scenario 1 (Table 6). As it is expected profitability of crop production using VRT relative to using URT has increased. As in Scenario 1 only in the case of Oxemann field crop production with VRT is more profitable than crop production with URT. However, in the case of other five fields, profitability of crop production using VRT relative to using URT has increased and falls in the range of 92% to 99%. In the case of Jones, Hess, and Clingenpeel fields, crop production using VRT is almost as profitable as crop production using URT. Therefore, if a producer has opportunity to pay less for field diagnostic services and VRT application, it may result in the situation when crop production using VRT will be at least as profitable as crop production using URT.

In the third scenario the 30 percent higher prices for P and K are used when both the results for VRT and URT cases are generated (Table 7). The pattern of profit distribution is similar to that of Scenario 1. Crop production using VRT is more profitable than using URT only in the case of Oxemann field. It should be noted that for this field in Scenario 3 profitability of VRT relative to URT is considerably higher than the same outcome in Scenario 1. In the case of all other five fields, crop production using VRT is less profitable than crop production using URT. In addition, the profitability of VRT relative to URT on these fields is lower than in Scenario 1. Therefore, higher P and K prices are not likely to change a relative profitability of crop production using VRT and crop production using URT. However, if crop production using VRT was more profitable than using URT in the scenario of lower P&K prices, it is likely to be even more profitable in the scenario of higher P&K prices. In the opposite situation (crop production using VRT is less profitable than using URT) higher P&K prices are likely to result in a larger difference in profitability levels of these two technologies.

Scenario 4 assumes the lower level of prices for field diagnostic services and VRT application and higher P&K prices in the case of VRT application. In the case of URT application, average prices for URT application and higher P&K prices are used. Under this set of assumptions, crop production using VRT is more profitable than crop production using URT only on Oxemann field (Table 8). The relative profitability of crop production using VRT and using URT in Scenario 4 is higher than in Scenario 1 and lower than in Scenario 2. In the case of Hess and Jones fields, crop production using VRT is almost as profitable as crop production using URT. In the case of all other fields the profitability of crop production using VRT relative to crop production using URT falls in the range of 88.16% to 94.88%. Therefore, in the situation of higher fertilizer prices and lower prices for field diagnostic services and VRT application, profitability of crop production using VRT is likely to increase.

Simulation results on profitability of crop production using information strategy are mixed. In the first scenario crop production using IT is the least profitable strategy in the case of four (Hess, Banta, Jones, and Clingenpeel) out of six fields. This is explained by the fact that the amount of fertilizer to be applied according to the IT requirement is approximately the same as under URT and/or VRT strategies. However, costs for field diagnostics services are incurred. These costs are approximately 2-3 times as high as costs of variable rate application (Table 2). Therefore, in this situation the benefits of using IT do not outweigh its costs relative to URT and VRT. Only in the case of Oxemann field crop production using IT is the most profitable strategy. Under the second scenario (lower prices for field diagnostic services and variable rate application), crop production using VRT is a more profitable strategy than crop production using IT. Under the third scenario (higher P&K prices), only in the case of Oxemann field crop production using IT is the most profitable strategy among all three strategies. This is explained by the fact that no fertilizer is recommended to apply. In summary, in the majority of cases crop production using IT is the least profitable strategy.

The important assumption underlining the level of profits for crop production using URT is that there is no cost for field diagnostic services. The averages of initial stocks of P&K were calculated using information on P&K content in each grid. Therefore, there exists some implicit cost for information gathering in the case of URT. This cost is not accounted in the analysis. Therefore, the level of profitability of crop production using URT is somewhat understated.

6. Conclusion

This study evaluates profitability of crop production using variable rate technology for P&K relative to profitability of crop production using uniform rate technology and information technology. To assess profitability of crop production we use data on soil characteristics relating to P&K content from six fields situated in Indiana, a site-specific crop response function for a corn-soybean rotation, and information on field diagnostic and variable rate application services.

In the case of one out of six fields crop production using VRT is a more profitable strategy than crop production using URT. In the case of the other five fields, the ratio of profitability of crop production using VRT relative to profitability of crop production using URT falls in the interval of 85-92%. In the scenario with lower prices for field diagnostic services and VRT application, profitability of crop production using VRT has increased relative to profitability of crop production using URT. The ratio of profitability of crop production with VRT to profitability of crop production using URT has increased, and falls in the range of 92-99%. Higher prices for P&K tend to increase profitability of crop production with VRT relative to profitability of crop production using URT, if the former was more profitable than the latter in the scenario with lower P&K prices. If crop production with VRT was less profitable than crop production using URT in the scenario of lower P&K prices, higher fertilizer prices lead to a larger difference between the profitability levels of these two technologies.

The simulated levels of profitability of crop production using VRT is affected by the field characteristics relating to P&K content. Crop production using VRT is likely to be more profitable than crop production using URT if the initial content of P and/or K is below the critical level in some grids and above the critical level in the other grids of the field. It is important to note the importance of the data on the initial P&K content used in the case of evaluation of crop production using URT. Any reasonable deviation from the average level of the nutrients characterizing fields under consideration may lead either to an increase or a decrease in profitability level of crop production using URT. In addition, profitability of crop production using URT was calculated using the assumption that there are no costs associated with gathering information. Although these costs are lower in the case of URT than in the case of VRT, ignoring this component in the analysis results in the overestimation of the profitability of crop production using URT. Crop production using information technology is the least profitable strategy in the majority of cases.

In summary, crop production using VRT may be a more profitable strategy than crop production using URT on the fields with certain characteristics. If prices for field diagnostic services and variable rate fertilizer application continue to be stable and even decline, as it has been observed recently, crop production using VRT is going to be even a more profitable strategy than crop production using URT.

References

Brouder, S., and J. Lowenberg-DeBoer. "Managing Long-Term Soil Fertility," in *Precision Farming Profitability*, J. Lowenberg-DeBoer and K. Erickson (Eds.), Purdue University Agricultural Research Programs, West Lafayette, IN, 2000: 30-42.

Dobbins, C.L., and W. Alan Miller. 2006 Purdue Crop Cost & Return Guide, Department of Agricultural Economics, Purdue University.
[http://www.agecon.purdue.edu/extension/pubs/id166_Feb06.pdf]

Dobbins, C.L., and W. Alan Miller. 2005 Purdue Crop Cost & Return Guide, Department of Agricultural Economics, Purdue University.
[http://www.agecon.purdue.edu/extension/pubs/crop_guide_05.pdf]

Griffin, T.W., J. Lowenberg-DeBoer, D.M. Lambert, J. Peone, T. Payne, and S.G. Daberkow. Adoption, Profitability, and Marketing Better Use of Precision Farming Data, Staff Paper #04-06, Department of Agricultural Economics, Purdue University, June 2004.
[http://agecon.lib.umn.edu/cgi-bin/pdf_view.pl?paperid=14656&ftype=.pdf]

Karr, M. "Spatial and Temporal Variability of Chemical Parameters," PhD dissertation, Purdue University, West Lafayette, IN, 1998.

Lowenberg-DeBoer, J., and M. Boehlje. "Revolution, Evolution or Dead-End: Economic Perspective on Precision Agriculture," in *Precision Agriculture*, P.C. Robert, R.J. Rust, and W.E. Larson (Eds.), ASA/CSSA/SSSA. 1996.

Lowenberg-DeBoer, J., and A. Aghib. "Average Returns and Risk Characteristics of Site Specific P and K Management: Eastern Corn Belt On-Farm Trial Results," *Journal of Production Agriculture*, Vol.12, No. 2, 1999.

McBride, W.D., and S.G. Daberkow. "Information and the Adoption of Precision Information Technologies," *Journal of Agribusiness*, 21, 1 (Spring 2003): 21-38.

Miller, A.W. and C.L. Dobbins. 2004 Purdue Crop Cost & Return Guide, Department of Agricultural Economics, Purdue University.
[http://www.agecon.purdue.edu/extension/pubs/crop_guide_04.pdf]

Miller, A.W. and C.L. Dobbins. 2003 Purdue Crop Cost & Return Guide, Department of Agricultural Economics, Purdue University.
[http://www.agecon.purdue.edu/extension/pubs/crop_guide_03.pdf]

Schnitkey, G., J. Hopkins, and L. Tweeten. "An Economic Evaluation of Precision Fertilizer Applications on Corn-Soybean Fields," Precision Agriculture: Proceedings of the 3rd International Conference. P.C. Robert, R.H. Rust and W.E. Larson (Eds.), American Society of Agronomy, Madison, WI, 1996: 977-987.

Swinton, S.M., and J. Lowenberg-DeBoer. "Evaluating the Profitability of Site-Specific Farming," *Journal of Production Agriculture*, Vol. 11, No. 4, 1998: 439-446.

Vitosh, M.L., J.W. Johnson, and D.B. Mengel. Tri-state Fertilizer Recommendations for Corn, Soybeans, Wheat and Alfalfa, Michigan State University, The Ohio State University, and Purdue University Extension Bulletin E-2567 (New), July 1995.

Whipker L.D., and J.T. Akridge. 2005 Precision Agricultural Services Dealership Survey Results, Staff Paper # 05-11, Department of Agricultural Economics, Purdue University, September 2005. [http://www.agriculture.purdue.edu/ssmc]

Whipker L.D., and J.T. Akridge. 2004 Precision Agricultural Services Dealership Survey Results, Staff Paper # 04-07, Department of Agricultural Economics, Purdue University, June 2004. [http://www.agriculture.purdue.edu/ssmc]

Whipker L.D., and J.T. Akridge. 2003 Precision Agricultural Services Dealership Survey Results, Staff Paper # 03-10, Department of Agricultural Economics, Purdue University, June 2003. [http://www.agriculture.purdue.edu/ssmc]

Whipker L.D., and J.T. Akridge. 2002 Precision Agricultural Services Dealership Survey Results, Staff Paper # 02-02, Department of Agricultural Economics, Purdue University, June 2002. [http://www.agriculture.purdue.edu/ssmc]

Table 1. Corn and Soybean Production Budgets.

Expenses and Prices	Units	2003 corn	2004 soybeans	2005 corn	2006 soybeans
Harvest price	$/bu	2.16	6.14	2.12	5.84
Variable costs					
Fertilizer (N and lime)	$/a	34.14	0.00	45.58	0.00
P&K	$/a	14.86	22.12	20.42	31.82
Seed	$/a	30.00	33.00	34.00	37.00
Chemicals	$/a	18.00	16.00	19.00	12.00
Dryer fuel & handling	$/a	15.00	1.00	17.00	1.00
Machinery fuel	$/a	10.00	10.00	12.00	17.00
Machinery repairs	$/a	9.00	9.00	10.00	10.00
Hauling	$/a	8.00	3.00	9.00	3.00
Interest	$/a	4.00	4.00	6.00	5.00
Insurance & misc.	$/a	11.00	8.00	11.00	8.00
Overhead					
Machinery replacement	$/a	52.10	52.10	52.10	52.10
Drying/handling	$/a	7.20	7.20	7.20	7.20
Family and hired labor	$/a	37.00	37.00	39.00	39.00
Land	$/a	125.00	128.00	129.00	134.00
Price of P	$/lb	0.22	0.28	0.30	0.36
Price of K	$/lb	0.13	0.14	0.18	0.22

Source: Crop Returns and Expenses Guides (Miller and Dobbins (2003 and 2004) and Dobbins and Miller (2005 and 2006)); data are for the average level of soil productivity. Fertilizer (N and lime) were calculated by the author by subtracting the value of P&K from the total expenses for fertilizer presented in the original sources.

Table 2. Field Diagnostic and Fertilizer Application Prices ($/acre).

Field diagnostic and fertilizer Application Services	Average	Minimum	Maximum
		2002	
Field diagnostics			
Soil sampling with GPS	7.30	2.50	11.00
Field mapping with GPS	4.54	0.50	10.00
Agronomic recommendations	2.61	0.00	6.00
Total diagnostic services	14.45	2.50	27.00
Fertilizer Application			
Traditional	n/a	n/a	n/a
GPS variable rate single product	5.81	3.00	8.50
GPS variable rate multiple product	7.67	5.00	10.00
		2003	
Field diagnostics			
Soil sampling with GPS	6.19	2.50	8.50
Field mapping with GPS	3.56	1.00	7.50
Agronomic recommendations	2.60	0.00	6.50
Total diagnostic services	12.35	3.50	22.50
Fertilizer Application			
Traditional	n/a	n/a	n/a
GPS variable rate single product	5.31	2.50	7.50
GPS variable rate multiple product	7.02	4.50	9.00
		2004	
Field diagnostics			
Soil sampling with GPS	5.91	2.00	8.50
Field mapping with GPS	4.00	0.50	7.50
Agronomic recommendations	1.62	0.00	4.00
Total diagnostic services	11.53	2.50	20.00
Fertilizer Application			
Traditional	4.58	3.00	6.00
GPS variable rate single product	5.37	3.25	7.50
GPS variable rate multiple product	6.95	3.75	9.50
		2005	
Field diagnostics			
Soil sampling with GPS	5.91	1.20	9.60
Field mapping with GPS	4.18	0.25	8.50
Agronomic recommendations	1.53	0.00	4.50
Total diagnostic services	11.62	1.45	22.6
Fertilizer Application			
Traditional	4.82	3.00	6.80
GPS variable rate single product	5.76	3.10	7.70
GPS variable rate multiple product	6.86	2.90	9.80

Source: Whipker and Akridge (2002, 2003, 2004, and 2005).

Table 3. Field Characteristics.

Characteristics	Units	Mylar	Clingenpeel	Hess	Oxemann	Banta	Jones
Width	meters	137.00	120.00	121.00	137.00	106.00	121.00
Length	meters	243.00	258.00	182.00	274.00	274.00	334.00
Grids	number	90.00	89.00	63.00	100.00	78.00	108.00
Field area	acres	8.22	7.65	5.44	9.27	7.17	9.98
Grid area	acres	0.09	0.08	0.06	0.10	0.08	0.11

The width, length, and the number of grids are taken from Karr (1988), Appendix 1.

Table 4. Soil Characteristics Relating to P&K Content.

	Mylar		Hess		Banta		Jones		Clingenpeel		Oxemann	
	Initial P&K content (lb/acre)											
	P	K	P	K	P	K	P	K	P	K	P	K
Mean	106	380	139	140	122	195	177	250	175	216	201	159
Median	107	371	130	134	119	156	214	227	157	187	214	152
Minimum	31	250	74	54	25	36	52	98	106	62	104	71
Maximum	200	606	214	339	214	597	214	535	382	642	214	455
St. dev	41	76	37	59	51	121	51	92	54	118	22	55
	Cation Exchange Capacity (CEC in cmol/kg) and Critical K level (lb/acre)											
P&K	CEC	K cr.	CEC	K cr.	CEC	K cr.	CEC	K cr.	CEC	K cr.	CEC	K cr.
Mean	6	182	5	173	5	176	7	184	9	197	2	161
Median	6	180	4	170	5	175	4	170	6	180	2	160
Minimum	3	165	2	160	1	155	1	155	2	160	1	155
Maximum	12	210	13	215	14	220	26	280	38	340	5	175
St. dev	2	9	2	11	3	17	7	33	9	46	1	4

Information on the initial content of P&K and cation exchange capacity corresponding to each grid in the case of each field is taken from Karr (1988), Appendix 1. Initial content of P&K is presented in kg/ha in the original source. The tests of P&K were taken at 0-10 cm depth. The descriptive statistics and critical values for K are calculated using this information. The methodology of calculation of the critical level for K is presented in Vitosh *et al* (1995).

Table 5. Scenario 1 Simulation Results. Hess, Oxemann, and Banta Fields.

Variable	Units	Hess			Oxemann			Banta		
		VRT	IT	URT	VRT	IT	URT	VRT	IT	URT
Revenue 1st year	$/field	1283.69	1283.72	1283.76	3120.44	3120.02	3127.43	2095.96	2089.61	2097.29
Revenue 2nd year	$/field	877.25	877.79	877.20	2183.87	2139.90	2136.98	1439.26	1420.35	1433.09
Revenue 3rd year	$/field	1124.44	1122.82	1124.57	2743.38	2710.29	2739.63	1832.89	1803.97	1837.19
Revenue 4th year	$/field	701.85	703.12	701.82	1774.70	1697.15	1709.73	1151.86	1111.35	1146.56
Total revenue	$	3987.23	3987.45	3987.35	9822.39	9667.35	9713.77	6519.97	6425.28	6514.13
Amount of P, 1st year	lb/field	0.00	0.00	0.00	96.26	0.00	0.00	85.16	0.00	0.00
Amount of K, 1st year	lb/field	3206.40	3412.10	3205.09	680.83	0.00	7117.04	4195.16	4855.55	3877.15
Amount of P, 3rd year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
Amount of K, 3rd year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.61	0.00
Cost of P, 1st year	$/field	0.00	0.00	0.00	21.18	0.00	0.00	18.74	0.00	0.00
Cost of K,1st year	$/field	416.83	443.57	416.66	88.51	0.00	925.22	545.37	631.22	504.03
Cost of P, 3rd year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Cost of K, 3rd year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	0.00
Total cost of P	$/field	0.00	0.00	0.00	21.18	0.00	0.00	18.76	0.00	0.00
Total cost of K	$/field	416.83	443.57	416.66	88.51	0.00	925.22	545.37	632.63	504.03
Total production cost	$/field	3566.01	3589.98	3516.07	7797.38	7622.62	8475.81	5719.62	5772.94	5567.57
Total P&K cost	$/field	416.83	443.57	416.66	109.69	0.00	925.22	564.13	632.63	504.03
Total SSM cost	$/field	67.20	64.42	17.43	179.56	114.48	42.46	120.42	105.25	28.47
Total other costs	$/field	3081.98	3081.98	3081.98	7508.14	7508.14	7508.14	5035.07	5035.07	5035.07
Cost of P&K/Total cost	%	11.69	12.36	11.85	1.41	0.00	10.92	9.86	10.96	9.05
Cost of SSM/Total cost	%	1.88	1.79	0.50	2.30	1.50	0.50	2.11	1.82	0.51
Total profit for the field	$	421.22	397.48	471.28	2025.01	2044.73	1237.96	800.35	652.33	946.56
Field size	acre	5.44	5.44	5.44	9.27	9.27	9.27	7.17	7.17	7.17
Profit per acre	$	77.44	73.07	86.64	218.40	220.53	133.52	111.56	90.93	131.94
Profit VRT/Profit URT	%	89.38			163.58			84.55		

VRT – the average price level for field diagnostic and variable rate fertilizer application services; IT – the average price level for field diagnostic services and the average price level for uniform fertilizer application; URT – the average price level for uniform fertilizer application.

Table 5 (cont.). Scenario 1 Simulation Results. Jones, Clingenpeel, and Mylar Fields.

Variable	Units	Jones			Clingenpeel			Mylar		
		VRT	IT	URT	VRT	IT	URT	VRT	IT	URT
Revenue 1st year	$/field	4038.08	4040.24	4040.71	2551.39	2552.21	2552.21	2726.59	2726.23	2722.47
Revenue 2nd year	$/field	2776.60	2763.64	2761.20	1755.34	1745.78	1743.94	1908.24	1869.81	1903.66
Revenue 3rd year	$/field	3543.14	3527.35	3539.76	2239.29	2229.23	2235.74	2397.13	2368.22	2407.06
Revenue 4th year	$/field	2232.34	2216.25	2209.26	1413.20	1401.23	1395.28	1550.71	1482.94	1550.80
Total revenue	$	12590.15	12547.48	12550.93	7959.21	7928.45	7927.18	8582.67	8447.20	8583.98
Amount of P, 1st year	lb/field	0.20	0.00	0.00	0.00	0.00	0.00	84.11	0.00	0.00
Amount of K, 1st year	lb/field	5336.23	6315.68	4837.62	4522.80	5353.99	4086.06	594.90	0.00	0.00
Amount of P, 3rd year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amount of K, 3rd year	lb/field	0.00	13.61	0.00	0.00	15.92	0.00	0.00	0.00	0.00
Cost of P, 1st year	$/field	0.04	0.00	0.00	0.00	0.00	0.00	18.50	0.00	0.00
Cost of K,1st year	$/field	693.71	821.04	628.89	587.96	696.02	531.19	77.34	0.00	0.00
Cost of P, 3rd year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost of K, 3rd year	$/field	0.00	2.22	0.00	0.00	2.60	0.00	0.00	0.00	0.00
Total cost of P	$/field	0.04	0.00	0.00	0.00	0.00	0.00	18.50	0.00	0.00
Total cost of K	$/field	693.71	823.26	628.89	587.96	698.62	531.19	77.34	0.00	0.00
Total production cost	$/field	10606.08	10726.84	10384.55	6848.75	6953.88	6693.03	6813.25	6660.54	6560.51
Total P&K cost	$/field	693.75	823.26	628.89	587.96	698.62	531.19	95.84	0.00	0.00
Total SSM cost	$/field	211.52	202.77	54.86	133.60	128.08	34.65	156.90	100.03	0.00
Total other costs	$/field	9700.80	9700.80	9700.80	6127.19	6127.19	6127.19	6560.51	6560.51	6560.51
Cost of P&K/Total cost	%	6.54	7.67	6.06	8.58	10.05	7.94	1.41	0.00	0.00
Cost of SSM/Total cost	%	1.99	1.89	0.53	1.95	1.84	0.52	2.30	1.50	0.00
Total profit for the field	$	1984.08	1820.64	2166.38	1110.46	974.57	1234.15	1769.42	1786.66	2023.47
Field size	acre	9.98	9.98	9.98	7.65	7.65	7.65	8.22	8.22	8.22
Profit per acre	$	198.76	182.39	217.02	145.21	127.44	161.39	215.26	217.36	246.16
Profit VRT/Profit URT	%	91.59			89.98			87.44		

VRT – the average price level for field diagnostic and variable rate fertilizer application services; IT – the average price level for field diagnostic services and the average price level for uniform fertilizer application; URT – the average price level for uniform fertilizer application.

Table 6. Scenario 2 Simulation Results. Hess, Oxemann, and Banta Fields.

Variable	Units	Hess			Oxemann			Banta		
		VRT	IT	URT	VRT	IT	URT	VRT	IT	URT
Revenue 1st year	$/field	1283.69	1283.72	1283.76	3120.44	3120.02	3127.43	2095.96	2089.61	2097.29
Revenue 2nd year	$/field	877.25	877.79	877.20	2183.87	2139.90	2136.98	1439.26	1420.35	1433.09
Revenue 3rd year	$/field	1124.44	1122.82	1124.57	2743.38	2710.29	2739.63	1832.89	1803.97	1837.19
Revenue 4th year	$/field	701.85	703.12	701.82	1774.70	1697.15	1709.73	1151.86	1111.35	1146.56
Total revenue	$	3987.23	3987.45	3987.35	9822.39	9667.35	9713.77	6519.97	6425.28	6514.13
Amount of P, 1st year	lb/field	0.00	0.00	0.00	96.26	0.00	0.00	85.16	0.00	0.00
Amount of K, 1st year	lb/field	3206.40	3412.10	3205.09	680.83	0.00	7117.04	4195.16	4855.55	3877.15
Amount of P, 3rd year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
Amount of K, 3rd year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.61	0.00
Cost of P, 1st year	$/field	0.00	0.00	0.00	21.18	0.00	0.00	18.74	0.00	0.00
Cost of K,1st year	$/field	416.83	443.57	416.66	88.51	0.00	925.22	545.37	631.22	504.03
Cost of P, 3rd year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Cost of K, 3rd year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	0.00
Total cost of P	$/field	0.00	0.00	0.00	21.18	0.00	0.00	18.76	0.00	0.00
Total cost of K	$/field	416.83	443.57	416.66	88.51	0.00	925.22	545.37	632.63	504.03
Total production cost	$/field	3521.64	3550.29	3516.07	7691.98	7540.58	8475.81	5648.93	5708.10	5567.57
Total P&K cost	$/field	416.83	443.57	416.66	109.69	0.00	925.22	564.13	632.63	504.03
Total SSM cost	$/field	22.83	24.73	17.43	74.16	32.44	42.46	49.73	40.41	28.47
Total other costs	$/field	3081.98	3081.98	3081.98	7508.14	7508.14	7508.14	5035.07	5035.07	5035.07
Cost of P&K/Total cost	%	11.84	12.49	11.85	1.43	0.00	10.92	9.99	11.08	9.05
Cost of SSM/Total cost	%	0.65	0.70	0.50	0.96	0.43	0.50	0.88	0.71	0.51
Total profit for the field	$	465.59	437.16	471.28	2130.41	2126.77	1237.96	871.04	717.17	946.56
Field size	acre	5.44	5.44	5.44	9.27	9.27	9.27	7.17	7.17	7.17
Profit per acre	$/acre	85.60	80.37	86.64	229.77	229.38	133.52	121.42	99.97	131.94
Profit VRT/Profit URT	%	98.79			172.09			92.02		

VRT – the minimum price level for field diagnostic and variable rate fertilizer application services; IT – the minimum price level for field diagnostic services and the minimum price level for uniform fertilizer application; URT – the average price level for uniform fertilizer application.

Table 6 (cont.). Scenario 2 Simulation Results. Jones, Clingenpeel, and Mylar Fields.

Variable	Units	Jones			Clingenpeel			Mylar		
		VRT	IT	URT	VRT	IT	URT	VRT	IT	URT
Revenue 1st year	$/field	4038.08	4040.24	4040.71	2551.39	2552.21	2552.21	2726.59	2726.23	2722.47
Revenue 2nd year	$/field	2776.60	2763.64	2761.20	1755.34	1745.78	1743.94	1908.24	1869.81	1903.66
Revenue 3rd year	$/field	3543.14	3527.35	3539.76	2239.29	2229.23	2235.74	2397.13	2368.22	2407.06
Revenue 4th year	$/field	2232.34	2216.25	2209.26	1413.20	1401.23	1395.28	1550.71	1482.94	1550.80
Total revenue	$	12590.15	12547.48	12550.93	7959.21	7928.45	7927.18	8582.67	8447.20	8583.98
Amount of P, 1st year	lb/field	0.20	0.00	0.00	0.00	0.00	0.00	84.11	0.00	0.00
Amount of K, 1st year	lb/field	5336.23	6315.68	4837.62	4522.80	5353.99	4086.06	594.90	0.00	0.00
Amount of P, 3rd year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amount of K, 3rd year	lb/field	0.00	13.61	0.00	0.00	15.92	0.00	0.00	0.00	0.00
Cost of P, 1st year	$/field	0.04	0.00	0.00	0.00	0.00	0.00	18.50	0.00	0.00
Cost of K,1st year	$/field	693.71	821.04	628.89	587.96	696.02	531.19	77.34	0.00	0.00
Cost of P, 3rd year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost of K, 3rd year	$/field	0.00	2.22	0.00	0.00	2.60	0.00	0.00	0.00	0.00
Total cost of P	$/field	0.04	0.00	0.00	0.00	0.00	0.00	18.50	0.00	0.00
Total cost of K	$/field	693.71	823.26	628.89	587.96	698.62	531.19	77.34	0.00	0.00
Total production cost	$/field	10466.42	10601.92	10384.55	6760.55	6874.98	6693.03	6721.15	6588.86	6560.51
Total P&K cost	$/field	693.75	823.26	628.89	587.96	698.62	531.19	95.84	0.00	0.00
Total SSM cost	$/field	71.86	77.85	54.86	45.39	49.17	34.65	64.80	28.35	0.00
Total other costs	$/field	9700.80	9700.80	9700.80	6127.19	6127.19	6127.19	6560.51	6560.51	6560.51
Cost of P&K/Total cost	%	6.63	7.77	6.06	8.70	10.16	7.94	1.43	0.00	0.00
Cost of SSM/Total cost	%	0.69	0.73	0.53	0.67	0.72	0.52	0.96	0.43	0.00
Total profit for the field	$	2123.73	1945.56	2166.38	1198.67	1053.47	1234.15	1861.52	1858.34	2023.47
Field size	acre	9.98	9.98	9.98	7.65	7.65	7.65	8.22	8.22	8.22
Profit per acre	$/acre	212.75	194.90	217.02	156.75	137.76	161.39	226.46	226.08	246.16
Profit VRT/Profit URT	%	98.03			97.13			92.00		

VRT – the minimum price level for field diagnostic and variable rate fertilizer application services; IT - the minimum price level for field diagnostic services and the minimum price level for uniform fertilizer application; URT – the average price level for uniform fertilizer application.

Table 7. Scenario 3 Simulation Results. Hess, Oxemann, and Banta Fields.

Variable	Units	Hess			Oxemann			Banta		
		VRT	IT	URT	VRT	IT	URT	VRT	IT	URT
Revenue 1st year	$/field	1283.59	1283.72	1283.76	3116.40	3120.02	3127.43	2095.47	2089.61	2097.28
Revenue 2nd year	$/field	854.50	853.31	854.18	2166.69	2139.90	2080.91	1406.03	1377.29	1395.52
Revenue 3rd year	$/field	1116.30	1115.59	1116.39	2734.51	2710.29	2719.69	1819.42	1793.47	1823.81
Revenue 4th year	$/field	667.82	668.23	667.41	1746.66	1697.15	1625.91	1101.32	1054.96	1090.40
Total revenue	$	3922.21	3920.85	3921.74	9764.26	9667.35	9553.94	6422.24	6315.33	6407.00
Amount of P, 1st year	lb/field	0.00	0.00	0.00	72.09	0.00	0.00	69.25	0.00	0.00
Amount of K, 1st year	lb/field	2753.09	2925.19	2747.14	327.99	0.00	6001.48	3545.04	4018.50	3129.65
Amount of P, 3rd year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amount of K, 3rd year	lb/field	14.28	32.97	14.90	0.82	0.00	36.27	18.02	89.00	24.15
Cost of P, 1st year	$/field	0.00	0.00	0.00	20.91	0.00	0.00	20.08	0.00	0.00
Cost of K,1st year	$/field	468.03	497.28	467.01	55.76	0.00	1020.25	602.66	683.15	532.04
Cost of P, 3rd year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost of K, 3rd year	$/field	2.98	6.88	3.11	0.17	0.00	7.57	3.76	18.57	5.04
Total cost of P	$/field	0.00	0.00	0.00	20.91	0.00	0.00	20.08	0.00	0.00
Total cost of K	$/field	471.00	504.16	470.12	55.93	0.00	1027.82	606.42	701.71	537.08
Total production cost	$/field	3620.19	3650.56	3569.53	7764.53	7622.62	8578.41	5781.98	5842.03	5600.62
Total P&K cost	$/field	471.00	504.16	470.12	76.83	0.00	1027.82	626.50	701.71	537.08
Total SSM cost	$/field	67.20	64.42	17.43	179.56	114.48	42.46	120.42	105.25	28.47
Total other costs	$/field	3081.98	3081.98	3081.98	7508.14	7508.14	7508.14	5035.07	5035.07	5035.07
Cost of P&K/Total cost	%	13.01	13.81	13.17	0.99	0.00	11.98	10.84	12.01	9.59
Cost of SSM/Total cost	%	1.86	1.76	0.49	2.31	1.50	0.49	2.08	1.80	0.51
Total profit for the field	$	302.03	270.29	352.21	1999.73	2044.73	975.52	640.25	473.30	806.39
Field size	acre	5.44	5.44	5.44	9.27	9.27	9.27	7.17	7.17	7.17
Profit per acre	$	55.53	49.69	64.75	215.68	220.53	105.21	89.25	65.98	112.41
Profit VRT/Profit URT	%	85.75			204.99			79.40		

In the case of all technologies prices for P&K are 30% higher than in Scenario 1. The average price level for field diagnostic services and fertilizer application is used.

Table 7 (cont.). Scenario 3 Simulation Results. Jones, Clingenpeel, and Mylar Fields.

Variable	Units	Jones			Clingenpeel			Mylar		
		VRT	IT	URT	VRT	IT	URT	VRT	IT	URT
Revenue 1st year	$/field	4036.40	4040.24	4040.24	2550.92	2552.21	2552.17	2723.07	2726.23	2722.47
Revenue 2nd year	$/field	2719.81	2682.07	2690.62	1717.39	1694.24	1698.34	1893.22	1869.81	1903.66
Revenue 3rd year	$/field	3522.30	3507.13	3513.67	2225.52	2216.48	2219.44	2389.38	2368.22	2407.06
Revenue 4th year	$/field	2147.04	2105.22	2103.08	1356.27	1331.10	1327.07	1526.21	1482.94	1550.80
Total revenue	$	12425.55	12334.66	12347.62	7850.10	7794.03	7797.02	8531.88	8447.20	8583.98
Amount of P, 1st year	lb/field	0.00	0.00	0.00	0.00	7794.03	0.00	62.99	0.00	0.00
Amount of K, 1st year	lb/field	4193.71	4699.41	3427.99	3763.88	4333.06	3178.42	286.59	0.00	0.00
Amount of P, 3rd year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amount of K, 3rd year	lb/field	30.63	166.01	37.73	22.09	112.25	28.82	0.71	0.00	0.00
Cost of P, 1st year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	18.27	0.00	0.00
Cost of K,1st year	$/field	712.93	798.90	582.76	639.86	736.62	540.33	48.72	0.00	0.00
Cost of P, 3rd year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost of K, 3rd year	$/field	6.39	34.63	7.87	4.61	23.42	6.01	0.15	0.00	0.00
Total cost of P	$/field	0.00	0.00	0.00	0.00	0.00	0.00	18.27	0.00	0.00
Total cost of K	$/field	719.32	833.53	590.63	644.47	760.04	546.34	48.87	0.00	0.00
Total production cost	$/field	10631.64	10737.11	10346.29	6905.26	7015.30	6708.18	6784.54	6660.54	6560.51
Total P&K cost	$/field	719.32	833.53	590.63	644.47	760.04	546.34	67.14	0.00	0.00
Total SSM cost	$/field	211.52	202.77	54.86	133.60	128.08	34.65	156.90	100.03	0.00
Total other costs	$/field	9700.80	9700.80	9700.80	6127.19	6127.19	6127.19	6560.51	6560.51	6560.51
Cost of P&K/Total cost	%	6.77	7.76	5.71	9.33	10.83	8.14	0.99	0.00	0.00
Cost of SSM/Total cost	%	1.99	1.89	0.53	1.93	1.83	0.52	2.31	1.50	0.00
Total profit for the field	$	1793.91	1597.55	2001.33	944.84	778.73	1088.84	1747.34	1786.66	2023.47
Field size	acre	9.98	9.98	9.98	7.65	7.65	7.65	8.22	8.22	8.22
Profit per acre	$	179.71	160.04	200.49	123.56	101.83	142.39	212.57	217.36	246.16
Profit VRT/Profit URT	%	89.64			86.77			86.35		

In the case of all technologies prices for P&K are 30% higher than in Scenario 1. The average price level for field diagnostic services and fertilizer application is used.

Table 8. Scenario 4 Simulation Results. Hess, Oxemann, and Banta Field.

Variable	Units	Hess			Oxemann			Banta		
		VRT	IT	URT	VRT	IT	URT	VRT	IT	URT
Revenue 1st year	$/field	1283.59	1283.72	1283.76	3116.4	3120.02	3127.43	2095.47	2089.61	2097.28
Revenue 2nd year	$/field	854.50	853.31	854.18	2166.69	2139.90	2080.91	1406.03	1377.29	1395.52
Revenue 3rd year	$/field	1116.30	1115.59	1116.39	2734.51	2710.29	2719.69	1819.42	1793.47	1823.81
Revenue 4th year	$/field	667.82	668.23	667.41	1746.66	1697.15	1625.91	1101.32	1054.96	1090.40
Total revenue	$	3922.21	3920.85	3921.74	9764.26	9667.35	9553.94	6422.24	6315.33	6407.00
Amount of P, 1st year	lb/field	0.00	0.00	0.00	72.09	0.00	0.00	69.25	0.00	0.00
Amount of K, 1st year	lb/field	2753.09	2925.19	2747.14	327.99	0.00	6001.48	3545.04	4018.50	3129.65
Amount of P, 3rd year	lb/field	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
Amount of K, 3rd year	lb/field	14.28	32.97	14.90	0.82	0.00	36.27	18.02	89.00	24.15
Cost of P, 1st year	$/field	0.00	0.00	0.00	20.91	0.00	0.00	20.08	0.00	0.00
Cost of K,1st year	$/field	468.03	497.28	467.01	55.76	0.00	1020.25	602.66	683.15	532.04
Cost of P, 3rd year	$/field	0.00	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00
Cost of K, 3rd year	$/field	2.98	6.88	3.11	0.17	0.00	7.57	3.76	18.57	5.04
Total cost of P	$/field	0.00	0.00	0.00	20.91	0.00	0.00	20.08	0.00	0.00
Total cost of K	$/field	471.00	504.16	470.12	55.93	0.00	1027.82	606.42	701.71	537.08
Total production cost	$/field	3575.82	3610.87	3569.53	7659.13	7540.58	8578.41	5711.30	5777.19	5600.62
Total P&K cost	$/field	471.00	504.16	470.12	76.83	0.00	1027.82	626.50	701.71	537.08
Total SSM cost	$/field	22.83	24.73	17.43	74.16	32.44	42.46	49.73	40.41	28.47
Total other costs	$/field	3081.98	3081.98	3081.98	7508.14	7508.14	7508.14	5035.07	5035.07	5035.07
Cost of P&K/Total cost	%	13.17	13.96	13.17	1	0.00	11.98	10.97	12.15	9.59
Cost of SSM/Total cost	%	0.64	0.68	0.49	0.97	0.43	0.49	0.87	0.70	0.51
Total profit for the field	$	346.39	309.98	352.21	2105.13	2126.77	975.52	710.93	538.14	806.39
Field size	acre	5.44	5.44	5.44	9.27	9.27	9.27	7.17	7.17	7.17
Profit per acre	$	63.68	56.99	64.75	227.04	229.38	105.21	99.10	75.01	112.41
Profit VRT/Profit URT	%	98.35			215.80			88.16		

VRT – the minimum price level for field diagnostic and variable rate fertilizer application services; IT – the minimum price level for field diagnostic services and the minimum price level for uniform fertilizer application; URT – the average price level for uniform fertilizer application; a higher level of P&K prices for all technologies.

Table 8 (cont.). Scenario 4 Simulation Results. Jones, Clingenpeel, and Mylar Fields.

Variable	Units	Jones			Clingenpeel			Mylar		
		VRT	IT	URT	VRT	IT	URT	VRT	IT	URT
Revenue 1st year	$/field	4036.40	4040.24	4040.24	2550.92	2552.21	2552.17	2723.07	2726.23	2722.47
Revenue 2nd year	$/field	2719.81	2682.07	2690.62	1717.39	1694.24	1698.34	1893.22	1869.81	1903.66
Revenue 3rd year	$/field	3522.30	3507.13	3513.67	2225.52	2216.48	2219.44	2389.38	2368.22	2407.06
Revenue 4th year	$/field	2147.04	2105.22	2103.08	1356.27	1331.10	1327.07	1526.21	1482.94	1550.80
Total revenue	$	12425.55	12334.66	12347.62	7850.10	7794.03	7797.02	8531.88	8447.20	8583.98
Amount of P, 1st year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	62.99	0.00	0.00
Amount of K, 1st year	lb/field	4193.71	4699.41	3427.99	3763.88	4333.06	3178.42	286.59	0.00	0.00
Amount of P, 3rd year	lb/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Amount of K, 3rd year	lb/field	30.63	166.01	37.73	22.09	112.25	28.82	0.71	0.00	0.00
Cost of P, 1st year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	18.27	0.00	0.00
Cost of K,1st year	$/field	712.93	798.90	582.76	639.86	736.62	540.33	48.72	0.00	0.00
Cost of P, 3rd year	$/field	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cost of K, 3rd year	$/field	6.39	34.63	7.87	4.61	23.42	6.01	0.15	0.00	0.00
Total cost of P	$/field	0.00	0.00	0.00	0.00	0.00	0.00	18.27	0.00	0.00
Total cost of K	$/field	719.32	833.53	590.63	644.47	760.04	546.34	48.87	0.00	0.00
Total production cost	$/field	10491.99	10612.19	10346.29	6817.05	6936.40	6708.18	6692.44	6588.86	6560.51
Total P&K cost	$/field	719.32	833.53	590.63	644.47	760.04	546.34	67.14	0.00	0.00
Total SSM cost	$/field	71.86	77.85	54.86	45.39	49.17	34.65	64.80	28.35	0.00
Total other costs	$/field	9700.80	9700.80	9700.80	6127.19	6127.19	6127.19	6560.51	6560.51	6560.51
Cost of P&K/Total cost	%	6.86	7.85	5.71	9.45	10.96	8.14	1.00	0.00	0.00
Cost of SSM/Total cost	%	0.68	0.73	0.53	0.67	0.71	0.52	0.97	0.43	0.00
Total profit for the field	$	1933.56	1722.47	2001.33	1033.05	857.63	1088.84	1839.44	1858.34	2023.47
Field size	acre	9.98	9.98	9.98	7.65	7.65	7.65	8.22	8.22	8.22
Profit per acre	$	193.70	172.55	200.49	135.09	112.15	142.39	223.78	226.08	246.16
Profit VRT/Profit URT	%	96.61			94.88			90.91		

VRT – the minimum price level for field diagnostic and variable rate fertilizer application services; IT – the minimum price level for field diagnostic services and the minimum price level for uniform fertilizer application; URT – the average price level for uniform fertilizer application; a higher level of P&K prices for all technologies.