Precision Farming -- Factors Influencing Profitability

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Site specific farming is an emerging technology with substantial promise to aid both farmers and society. These methods, also variously referred to as *Precision Farming*, *Variable Rate Application Farming*, and *Prescription Farming*, allow application of inputs to a specific cropland area based on soil type, fertility levels, and other endowments of that site. The site specific management (SSM) concept is based on the ability to repeatedly locate a position within a field. Site specific farming incorporates four technologies: Remote sensing, geographic information systems (GIS), global positioning systems (GPS), and process control. Remote sensing data have been used for several years to distinguish crop species and locate stress conditions in the field. Other remote sensing applications of SSM include yield monitors, moisture sensors, and soil nutrient sensors. GPS is a navigation system based on a network of earth-orbiting satellites that lets users record near-instantaneous positional information (latitude, longitude, and elevation) with accuracy ranging from 100m to 0.01m (Lang, 1992). GPS allows the manager to reliably identify field locations so that inputs can be applied to individual field segments based on performance criteria and previous input applications. GIS technology allows the manager to store field input and output data as separate map layers in a digital map and to retrieve and utilize these data for future input allocation decisions. Process control technologies allow information drawn from the GIS to control processes such as fertilizer application, seeding rates, and herbicide selection and application rate, thus providing for variable rate application technologies (VRT).

The National Research Council Committee on Assessing Crop Yield: Site-Specific Farming, Information Systems, and Research Opportunities, defined site-specific management as "a management strategy that uses information technologies to bring data from multiple sources to bear on decisions associated with crop production" (p.2). They correctly recognized that SSM is not a single technology, but rather a suite of technologies that allow 1.) capture of data at an appropriate scale and time, 2.) interpretation and analysis of that data to support a range of management decisions, and 3.) implementation of a management response at an appropriate scale and time.

In the remainder of this paper I will review recent research into farm-level economics and environmental impacts of SSM, and identify those factors that are likely to impact the profitability of the farm firm with adoption of SSM. I will explore the likely impact of farm size on the cost of owning and operating the SSM system and the potential impacts of widespread adoption of SSM on the size structure of agriculture. I will also present a hypothetical example to explore the economic value that might be derived from grid soil sampling and variable rate application of fertilizer and suggest potential environmental benefits.

Previous Research

Swinton and Lowenberg-DeBoer compared profitability estimates for variable rate application of fertilizers in nine studies. These studies represented profit comparisons for 54 sites. Information (soil sampling) costs were added for those studies that did not recognize this charge. They reported that 57 percent of the sites studied produced greater profits for the SSM regime than for a uniform rate technology (URT).

Babcock and Pautsch evaluated the profitability of VRT nitrogen fertilization relative to a uniform rate application in [1]2 randomly selected Iowa counties. They concluded that the economic and environmental impacts of moving from URT to VRT depended heavily on the inherent yield variability in fields. They found modest increases in returns above fertilizer costs. The majority of this benefit was for a reduction in fertilizer costs rather than an increase in yields. They suggest that reduced nitrogen usage will correspond to a reduction in nitrate leaching and associated external costs.

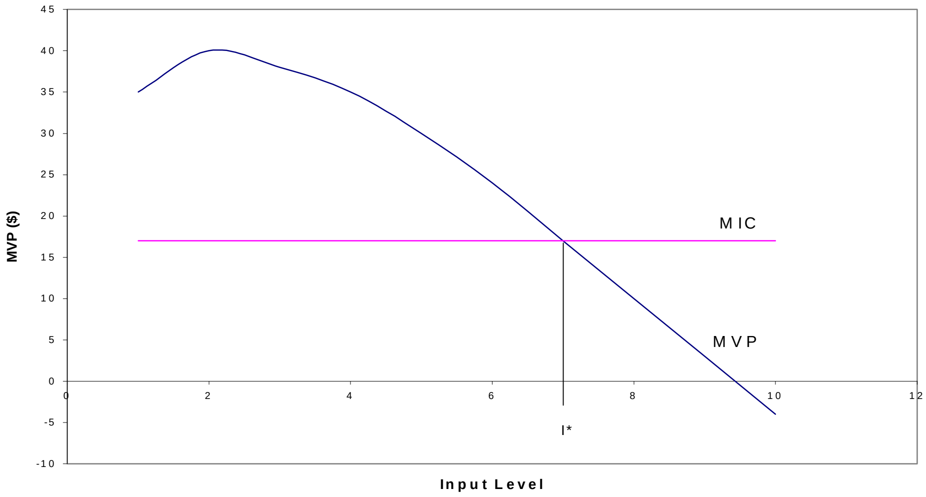
Watkins, et al. performed a similar analysis of farm and environmental economics of VRT application of nitrogen fertilizers in seed potato production in Idaho. VRT fertilizer applications resulted in decreased profits relative to conventional fertilizer application strategies. They estimated that nitrate losses from the field were virtually the same for VRT and URT application methods.

Oriade, et al. studied weed control with post-emergence herbicides. They evaluated two application techniques -- uniform rate application of the herbicides over the full field and uniform rate application of herbicides for selected portions of the field (spot spraying). They also considered alternative levels of weed populations and weed *patchiness*. Weed patchiness was the most important factor influencing the profitability of SSM of herbicides. They also considered the environmental consequences of the two management methods. Environmental benefits of SSM increased with increased weed populations and increased patchiness of the weeds.

Farm-Level Economic Impacts of Site-Specific Farming

The adoption of site-specific farming practices will likely result in significant economic consequences at the farm level. However, because these technologies are just now emerging, we do not have solid estimates of resulting changes in costs and returns. Furthermore, farmers and industry personnel are still learning how to implement these systems. Thus, we expect the costs and returns to change over time as the technology and our understanding of how to use it change.

Figure 1. Optimal Input Use for a Single Variable Input.



A simple economic model can be used to demonstrate the potential for changes in both revenues and input costs. Figure 1 represents the marginal productivity of alternative levels of an input in production of some crop. The marginal value productivity (MVP) of the variable input represents the <u>additional</u> value (product of added yield and price) resulting from the last unit of input. The MVP curve in figure 1 is downward sloped as suggested by the law of diminishing returns. Marginal input cost (MIC) represents the cost of an additional unit of the variable input. The economic efficient (profit maximizing) level of input usage (I^*) is identified by the intersection of MVP and MIC. This is the point at which the value produced by the last unit of input is exactly equal to the cost of the last unit of input.

Figure 2. Optimal Input Allocation for Soils of Differing Productivity.

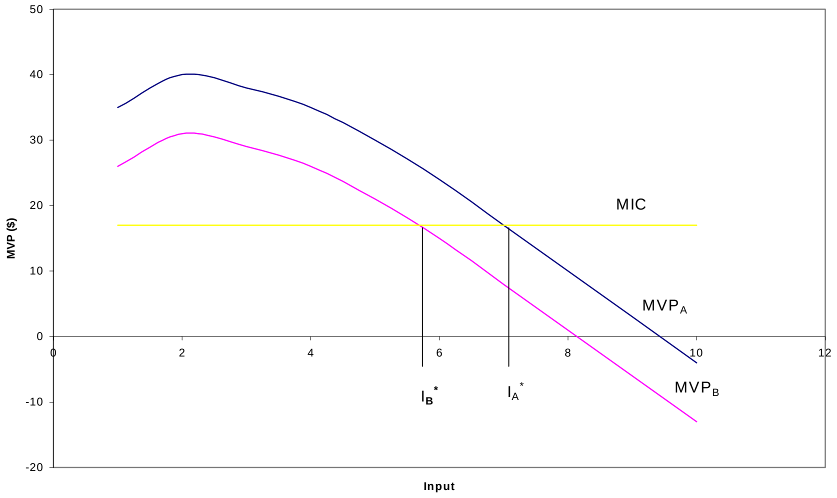


Figure 2 extends this model to consider two soils with differing productivity with respect to the variable input. Soil A has greater productivity than soil B -- MVP_A is greater than MVP_B at all levels of input usage. I_A^* and I_B^* represent the optimal allocation of input on soils A and B, respectively. If a single soil test is made and a single rate of input is applied, an uneconomic allocation will be made for a portion of the land base. If the soil test is drawn from soil A, I_A^* will be applied to both soils. This represents an over-application of the input on soil B. In the event that the soil sample is drawn from soil B, inputs are applied to all soils at the rate I_B^*, resulting in an under-application of the input on soil A. In the event that soil cores are drawn from both types of soil and mixed prior to determining the input rate recommendation, the resulting rate will be between I_A^* and I_B^*, and will represent the optimal input usage on neither soil.

SSM recognizes the different input requirements of the two soils. Provided that the two soils are identified correctly and soil samples are drawn from each, an optimal input allocation would be made for each soil. Relative to applying I_A^* on both soil types, SSM results in both a decrease of input cost (rates are lowered to I_B^* on soil B) and a decrease in yield on soil B due to the reduced input. Note also that SSM results in a decrease in environmental damages because the over-application of input on soil B is eliminated. In the event that I_B^* is applied on all soils with a URT, SSM results in both an increase in input costs and an increase in yields on type A soils.

From the previous discussion, it is clear that both revenues and costs will be altered by SSM. In the following, I outline the sources of costs and returns facing the farmer who adopts SSM. I will assume that the decision rules used to manage the SSM system are primarily focused on the maximization of farm profitability.

Returns:

In the absence of subsidies or other extra-market payments to the farmer, the only source of returns to the farmer for adoption of SSM technologies is in the value of the crop. Total gross receipts to the cropping enterprise is the product of crop yield, price, and the number of acres harvested. The specific farm situation to which the technology is applied and how the individual farmer chooses to manage the technology will determine the impact on each of these parameters.

Clearly, yield will be impacted by the application of SSM. However, it is difficult to argue the direction of change for this parameter. In Table 1, I suggest that average yields could increase, decrease, or remain approximately constant. It is almost certain that, with application of an SSM that allows regulation of several inputs, yields on some sites (field locations) will increase while others will decrease. That is, SSM will allow identification of both areas of uneconomic over- and under-application of inputs. While SSM may reduce the variability of yields across the farm, it is not possible to predict the direction of change on average yields.

Table 1. Crop Enterprise Budget with Addition of Precision Farming Technology

Returns: (price*yield*acreage)	
Yield	Constant, increase or decrease
Price	Constant or increasing
Acres	Constant or decrease
Total Returns	???
Variable Costs:	
Data costs (Grid sampling, mapping, remote sensing)	Increase
Fertilizer/lime material costs	Constant, increase or decrease
Fertilizer/lime application fees	Increase
Pesticide material costs	Constant, increase or decrease
Pesticide application fees	Increase
Total Variable Costs	???
Fixed costs:	
Depreciation	Increase
Interest on Investment	Increase
Development of management *human capital*	Increase
Total Fixed costs	Increase
Profit	???

Price received clearly will impact gross receipts. Assuming that the farm was reasonably well managed prior to SSM adoption, crop quality for most crops is not likely to change sufficiently to impact price. In Table 1, however, I suggest a potential for increased commodity price with SSM. If crops are grown that have special characteristics (e.g., high lysine corn, organic crops, etc) that will command premium prices, SSM allows improved ability to *preserve the identity* of these crops. Note, however, that this is not an automatic consequence of SSM, but rather is an opportunity afforded to the adopter.

The number of acres harvested is also an important determinant of total receipts. In Table 1, I suggest that harvested acreage is likely to remain constant or decrease with SSM adoption. SSM technologies are management intensive. Assuming that the farm manager provides much of the decisionmaking and that the farm manager was fully employed prior to SSM adoption, he/she may be challenged to maintain the existing acreage. Over the next decade we are likely to see new technological innovations that will release this restraint on farm size. For example, if on-the-go soil tests and other forms of diagnostic/prescriptive remote sensing are developed many of the analytical and decision processes can be automated, greatly reducing manager time requirements of SSM.

The direction of change of farm total gross receipts is indeterminate (Table 1). It will depend on the relative increase or decrease in average yields, change in commodity prices, and change in enterprise size. These, in turn, will be influenced by site-specific factors. As we gain more experience with SSM, scientists will be better able to judge the relative contribution of each of these parameters.

Costs:

There are two broad categories of cost that must be borne by the farmer. *Variable* costs are a function of the level of output of the farm. *Fixed* costs are invariant with changes in farm output. The adoption of a site-specific management system is expected to result in changes in both of these cost categories.

Variable Costs:

Data Acquisition Costs: Site specific management is an information intensive technology. As such, data acquisition costs will be substantial, at least for early forms of the technology. Georeferenced soil sampling and scouting for weed, insect, and disease pests can represent sizeable production expenses. Data purchase, subscriptions, consulting fees and data management costs also can be significant. For instance, anecdotal evidence from conversations with industry personnel suggest grid sampling costs of $2.50 per acre (three acre grids), soil test lab fees of $5.50 per sample ($9.50 for samples with micronutrient evaluations), $3.00 per acre for georeferenced field scouting, and $0.50 per acre for generation of yield maps.

There are a number of technological developments that could substantially lessen data costs. Remote sensing using satellite-based photography may be substantially less costly that field scouting and soil sampling provide, of course, that reliable interpretation of such imagery can be developed. More promising still would be the development of on-the-go sensors that would allow measures of soil fertility, identification of weeds, or other problems at the time of planting, spraying or other operation. Such developments would reduce the variable costs of data acquisition, labor, and management, but would increase capital investment and fixed costs. On-the-go sensors would also go a long way toward relinquishing the restraints on farm size mentioned earlier.

Fertilizers: Fertilizers, including agricultural lime, represent a sizable cost item for crop producers. However, the direction of change for this cost category is not clear (table 1). For sites that have had a history of uneconomical over-application of nutrients or simply have a soil type that is nutrient rich, grid sampling may reveal that fertilizer applications can be reduced. Other sites, perhaps within the same field or farm, may reveal that nutrient application rates should be increased from the uniform rates previously applied. Thus the sign for fertilizer material costs will vary by site and circumstance.

Agricultural lime may be a case where input levels can be expected to diminish with variable rate application. Soil pH has been found to vary substantially within fields. Site-specific management of this input may result in zero application of lime over portions of the field, saving material costs and, potentially, reducing application costs. In fact, variable rate lime application has become the *posterboy* for the variable rate fertilizer industry. It is often the first service sold to farmers.

Fertilizer application costs will clearly increase with SSM (table 1). Anecdotal evidence suggests that service firms charge a premium of $2.00 or more for variable rate application of fertilizers relative to a uniform application. Even if the individual owns the variable rate application equipment, application costs are expected to rise to due increased labor costs associated with the application.

Pesticides/herbicides: Herbicides and pesticides also represent a major share of crop production costs. Although variable rate application of these inputs is still in its infancy, logic would suggest that there is potential for sizable economic return from SSM. Postemergence herbicides, much like agricultural lime, may benefit from the site clustering of the input needs. If weeds are *patchy*, spot spraying may be an option so that at many sites herbicide applications will be zero. Gains may also be possible for preemergence herbicides. Research has suggested that different rates of herbicide application may be required on different soils. Thus, a variable rate application of these materials based on soil type and other parameters may allow cost savings. Although the potential may be ripe for herbicide/pesticide cost savings, the amounts of these inputs applied will be a site-specific decision. On some sites application rates may increase from the current (uniform) applications level. It is also clear that the costs of scouting and variable rate application will rise relative to the uniform application strategy.

Other variable inputs: There are a number of other inputs that can be regulated according to specific site conditions. Seed varieties and planting populations can be varied with soil type, slope, moisture conditions and other parameters provided that measurements for these parameters are available at planting time and that an algorithm exists with which to regulate the variety/rate selection. Because soils vary across the field, there may be substantial payoff to varying seeding rates/varieties with soil conditions across the field.

Labor and management are inputs that will not be regulated by the SSM technology, but rather are required inputs. SSM is an information technology. With the current state of the technology, human intervention in the decision process is quite important, and implies a substantial time commitment on the part of the manager. Thus, in table 1 I have suggested that these input costs will increase with SSM adoption.

Fixed Costs:

Fixed costs represent those inputs that are invariant with the level of production. Generally, these are annualized costs associated with <u>durable</u> capital investments. For instance, the depreciation, interest on investment, and insurance costs associated with durable capital such as yield monitors, computers and software, GPS equipment, VRT application equipment, and other necessary equipment.

Some farmers may choose to use financial leasing or custom hire (operating lease) in lieu of ownership for some durable assets. In the case of a financial lease, the farmer will face a fixed financial lease payment instead of a charge for depreciation and interest on invested capital. A farmer may elect to custom hire the variable rate application of fertilizers instead of owning VRT equipment. Generally, such operating leases are offered on a variable cost basis -- priced per acre or per day of operation. In this case, the full costs of VRT application are variable and appear in the fertilizer/lime/herbicides application fees in table 1.

Boundary mapping, soil and site surveys and the establishment of base maps also may represent a substantial expenditure. These too should be viewed as durable investments and their costs should be amortized as a fixed cost over a number of years. There is also a fixed cost associated with management. In particular, the cost of developing *human capital* is often omitted from the cost equation. Typically, there is a substantial learning process required prior to the effective use of the SSM system. The development of the knowledge base required to manage such a system may be substantial.

Profit:

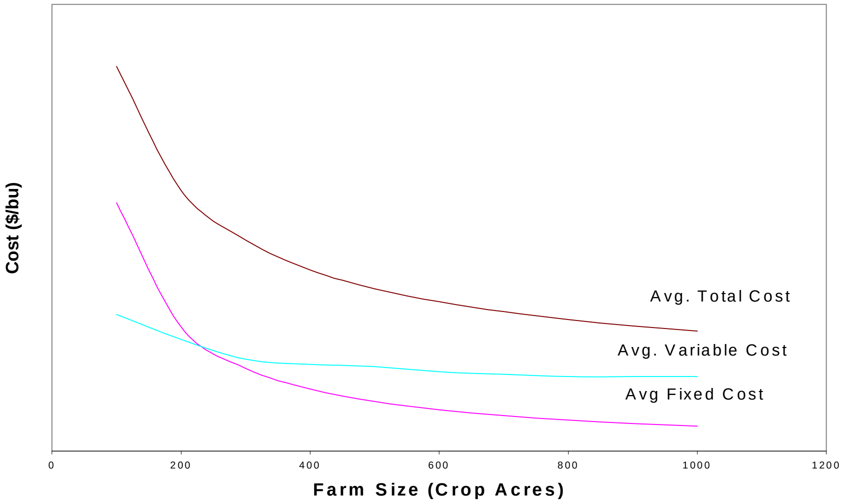
Profits are the difference in total receipts and total costs. The change in profits with the addition of SSM technologies cannot be determined in general -- it depends on the circumstances for the specific farm. Total receipts will either rise or fall with SSM adoption for a particular farm. Similarly, variable costs can either rise or fall, depending on the magnitude of input savings (if any) realized with SSM. Only fixed costs are predictable, rising with SSM adoption. The change in profit will depend on the relative magnitude of changes in the cost and revenue categories.

Economies of Scale and SSM:

Table 1 describes the expected sources of costs and revenues for any farm adopting SSM. However, the relative magnitude of these cost changes will not be the same for all farms. Farm size is an important modifier of average cost relationships. Figure 3 summarizes the expected relationship of per acre variable and fixed costs for farms of differing sizes.

Figure 3 is drawn with variable costs that diminish modestly with increased farm size. Although many of the variable inputs may be priced at constant price regardless of quantity purchases, other inputs or services may include volume discounts. For instance, the variable rate fertilizer applicator may charge different rates per acre for 100 acres of application versus 1,000 acres.

Figure 3. Expected Average Cost Relationships for Site-Specific Management Technologies.



The average fixed cost curve declines dramatically with increased farm size. If total fixed costs (e.g., the cost of owning the GPS, computer, mapping software, etc.) are equal for small and large farms, average (per acre) fixed costs are 10 times larger for the 100 acre farm than for the 1,000 acre farm.

The average total cost curve represents the total of average variable and average fixed costs. Clearly, it shape is determine primarily by the shape of the average fixed cost curve. The decline in average total costs with the expansion of farm size is referred to as economies of scale. Such economies are likely to exist for site-specific management technologies and will make adoption of this technology more profitably for larger than for smaller farms.

The Value of Information and Variable Rate Application

In this section, I will explore the value of SSM in the regulation of a single variable input. I will demonstrate that site-specific information about local conditions (e.g., soil test data) may have value to the decisionmaker even if a uniform rate application is used. Variable rate application of the input may or may not provide additional economic value.

As an example, I will consider the case of a 21-acre field with 7 equal-sized management units (grids). This field has variability of soil type and soil phosphorus levels that is not atypical of many real-world situations. The single input to be varied is phosphate fertilizer. Soil phosphorus test levels for each field unit are presented in table 2 as are the P_2O_5 application recommendations. Soil phosphorus levels range from the 20 to 70 lbs/ac across the field. The average soil phosphorus level for the seven field units is 40.4. Recommended P_2O_5 fertilization rates range from 0 to 129 pounds per acre across the seven management units. The average of these seven fertilization rates is 57.9 pounds per acre. Also presented in table 2 are expected crop yields for each field unit without phosphorus fertilizers and for three alternative P_2O_5 fertilization regimes.

Table 2. Soil Test Results and Recommended P_2O_5 Application Rates for Seven Field Management Units.

	Field Unit (3.0 acres each)							Average
	1	2	3	4	5	6	7	
Bray 1 Soil Phosphorus test (lb/ac)	70	20	62	25	30	31	45	40.4
Recommended pounds P_2O_5 per acre	0	129	0	106	82	77	11	57.9
Yield with VRT application of P_2O_5	219	200	214	200	200	200	200	204.7
Yield with 58 lb uniform rate of P_2O_5	230	173	230	184	193	194	210	202.0
Yield with 93 lb uniform rate of P_2O_5	230	188	230	196	203	204	216	209.6
Yield Without Additional Phosphorus	219	132	214	152	167	169	197	178.6

The base case represents corn production with the usual practice of a single soil test per field with uniform rate application of fertilizers. If three soil cores are taken from management units 2, 4, and 6, and mixed (averaged) prior to testing, the resulting soil phosphorus test result is 25.3 pounds per acre. This will result in a recommended P_2O_5 application of 93 pounds per acre. Notice that if, by chance, the soil cores are drawn from a different part of the field, say management units 1, 3, 5 and 7, the average soil phosphorus level is 51.8. The recommended P_2O_5 application rate for this sample is zero pounds per acre. Clearly, for a field with the variability of the example, the recommended application rates for a single soil test vary significantly depending on the location of the soil cores drawn for the sample. If the grid soil test results are treated as *truth*, the single soil test based on cores from grids 2, 4, and 6 result in an over-application of P_2O_5 (93 pounds for the single soil test versus an average of 57.9 pounds for the VRT method). Conversely, if the single soil test is based on cores from grids 1, 3, 5 and 7, phosphate fertilizer is under-applied by 57.9 pounds.

Expected corn yields also will vary dramatically under the three fertilizer application regimes. If no phospate fertilizers are applied (the recommendation if the soil sample is drawn from grids 1, 3, 5, and 7), yields will vary from 132 to 219 bushel per acre with a mean of 178.6

bu/acre (table 2). If 93 pounds of P_2O_5 are applied, the yield range is 188 to 230 bu/acre with a mean of 209.6. If the P_2O_5 recommendation is based on the average of the VRT phosphate rates (57.9 pound per acre) but the fertilizer material is applied at uniform rate across the field, the yield range is 173 to 230 bu/ac, with a mean of 202 bu/ac. The VRT application narrows the yield distribution to a range of 200 to 219 bu/ac, with a mean yield of 204.7. In this case, VRT reduces substantially the average application rate of phosphate fertilizer, but also results in a somewhat lower average yield.

Variable input cost assumptions for the example are listed in table 3. Assume that the soil tests are drawn for general fertility decisions rather than to support the phosphorus fertilizer decision only. The single soil test will include both primary and micronutrient analyses at a cost of $9.50 per sample. For the grid sampling scenario, one sample will include micronutrient analysis and the remaining six only primary nutrient analysis at a cost of $5.50.[1] The costs of uniform rate and variable rate fertilizer applications are $3.00 and $5.00 per acre, respectively.

Table 3. Price Assumptions for the P_2O_5 Application Problem.

Cost Of P_2O_5 Material Per Ton	$0.25
Cost Of Soil Test (Primary Nutrients Only)	5.50
Cost Of Single Soil Test (With Micronutrient Analysis)	9.50
Cost Of VRT P_2O_5 Application/Acre	5.00
Cost Of Uniform Rate P_2O_5 Application/Acre	3.00
Price of Corn ($/bu)	2.75

P_2O_5 application costs and returns for the 21 acre field under three fertilizer application regimes are presented in table 4. The base case scenario, a uniform rate of application based on a single soil test (grids 2, 4, and 6) results in a value of yield improvement from P_2O_5 (relative to zero P_2O_5) of $597. Although the soil sample costs are one-fourth those of a grid soil sample based regime and P_2O_5 application fees are three-fifths those of a variable rate application regime, P_2O_5 material costs are much larger ($488). Net returns for the 21 acre filed are $45 larger than if no soil test were made and no fertilizer material was applied.

The second scenario assumes that grid sampling is performed, but P_2O_5 is applied at a uniform rate based on the average of the seven liming recommendations. This results in an application of 58 pounds per acre of P_2O_5 at cost of $304 of material. Although the application costs are the same as for the previous scenario, soil sampling costs are larger. The costs of this fertilizer application scenario total $371. The net return to the field, again relative to no fertilizer, is $80. The difference in the net return for uniform rate application based on the grid sampled data ($80) and the net return for the single soil test scenario ($45) is the value of information derived from the grid soil test ($35).

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[1] The standard contract offered by one Central-Ohio service provider suggests that every sixth sample drawn will be analyzed for micronutrient content.

Table 4. P_2O_5 Fertilization Costs Under Three Application Regimes.

	P_2O_5 Material	Soil Sample Costs[a]	Application Fees	Value of Yield Improvement[b]	Total
Single Sample, Uniform Rate Application: Sample cores from grids 2, 4 & 6	$488	$1	$63	$597	$45
Single Sample, Uniform Rate Application: Sample cores from grids 1, 3, 5 & 7	0	1	0	0	-1
Grid Sample, Uniform Rate Application	304	4	63	451	80
Grid Sample, Variable Rate Application	304	4	105	503	91

a. Soil sample costs are assumed to be divided equally among four fertility decisions (Nitrogen, Phosphorus, Potassium and Lime) and are annualized over 3 years.
b. Yield improvement relative to no P_2O_5 fertilization.

The final scenario considers the addition of variable-rate application of fertilizer. Soil test costs are the same as the previous scenario. However, fertilizer application rates will vary for each of the 7 grids and application costs are higher. Total cost of the material is $304. Total cost of the application under this scenario is $413. Net return for the 21 acre field, relative to no application of fertilizers, is $91. Thus the variable rate application increases net returns by $11 for the 21 acre field relative to the uniform rate application based on grid sample information.

Environmental Consequences and Externalities

Agriculture, like other industries, has the potential to create pollution or other external costs to society. SSM has the potential to either increase or decrease the magnitude of agricultural externalities, depending on the relative increase or decrease in fertilizers, herbicides, and other agrichemical inputs. The profit-maximizing producer will not recognize these external costs. However, if policymakers were to impose taxes or other mechanisms to charge (internalize) these costs to farmers, such taxes (subsidies) would become a private cost (benefit) and would be included in the individual farmer's profit calculation.

Examination of the hypothetical case presented in the previous section will give some insight as to changes with SSM that might impact the environment. The quantity of P_2O_5 applied varied substantially among treatment regimes (table 4). The two single sample - uniform rate application scenarios applied P_2O_5 fertilizer in a range of 0 to 93 pounds per acre. The grid sample - uniform rate application and VRT application resulted in the same total P application per acre (57.9 pounds per acre), however this was allocated differentially among the management units in the VRT regime. Soil P after application of P_2O_5 ranged from 29 to 79 pounds per acre across individual management units with the single sample - uniform rate app (base case).[2] The range of soil P for the grid sample - uniform app is 26 to 76 pounds per acre. For the VRT application, this range is only 33-70 pounds per acre. To the extent that environmental pollution hazard is correlated with soil P levels, environmental damages are lower with VRT versus URT application of fertilizer nutrients in the hypothetical case.

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[2] One pound of P_2O_5 will raise the soil P test about 0.1 pounds (Ohio Cooperative Extension Service).

Summary and Conclusions

Site-specific management does have the potential to both improve the profitability of the farm and to lessen environmental damages of agriculture. The farm level economic performance of SSM is site-specific. It's financial performance will depend on the attributes of the farm's soils and other resources, the inherent variability in production for these resources, and previous management decisions. Yields likely will increase on some field sites and decrease on others relative to a uniform input application strategy. Likewise the level of usage of fertilizers, pesticides and other inputs will vary unpredictably relative to URT. Farm total fixed costs are predicted to rise with SSM due to durable investments in machinery, mapping and resource inventories, and human capital. Profits associated with the SSM investment will be determined by the relative changes in revenues and costs.

The costs and profits of SSM will also be impacted by the size of the adopting farm. Economies of scale will be important for this technology as with any capital embodied technology. Larger farmers will have a greater profit potential, and thus will predominate the early adopters of this technology. This may also mean that SSM, ultimately, will accelerate the trend toward fewer and larger farms.

Environmental impacts also are likely. Because fertilizer and agrichemical input usage can either increase or decrease with SSM adoption, it is difficult to suggest how important this technology will be to reducing the environmental damages from agriculture. However, there is reason to believe that SSM will result in less variability of these inputs applied at individual sites.

Environmental costs and benefits are external to the farm firm. Farmers, when making the SSM adoption decision, will not necessarily consider these values. If it is determined that SSM has significant environmental value to society, adoption could be speeded by either transferring external costs back to nonadopter farmers through a tax mechanism, or rewarding adopters with a subsidy.

In the above discussion, it has been assumed that the decision rules for input allocation in the SSM are to maximize private profits. An alternative would be to develop rules that would maximize a joint function of profits and environmental benefits or, more simply, to maximize private profits subject to some environmental constraints on input usage. Such an implementation would use the power of SSM to directly impact environmental quality. However, use of such rules would limit farmers' profit potential for the new technology. To encourage adoption of such environmental friendly input allocation rules, transfer payments or tax credits could be granted for compliance.

There is need for additional research to understand both the private economics and societal issues. SSM will alter input usage at individual sites within a field. Average input usage may not vary greatly between SSM and uniform rate applications across the field. This begs the question of what is the environmental benefit of targeting fertilizers and pesticides and, effectively, decreasing the variability of rates of application across the field and farm. It is likely that reduced variability of input usage will impact the environment's ability to assimilate agrichemical and fertilizer inputs. However, it is not clear how one would aggregate such site level impacts into an estimate of environmental benefits for a farm, watershed, or larger unit.

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