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In-field Spatial Variability and Profitability of Precision Nitrogen Application On Corn in Buchanan County, Iowa

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Abstract:

Despite the intuitive appeal of precision farming, adoption of precision technology options has been well below expectations. A review of precision farming studies suggests as expected that precision farming becomes more profitable as in-field spatial variability increases. However, no studies have attempted to quantify infield variability at any reasonable scale beyond a few experimental fields.

This study contributes to the assessment of precision farming by introducing an approach that can help characterize the relative profitability of precision farming methods as compared to conventional farming. Using readily available geographic information systems databases on crop cover, soil type, and weather, we assess the viability of precision nitrogen applications on corn in Buchanan County, Iowa. We find little evidence for viability of precision nitrogen applications in contrast to uniform application rates, largely because of the lack of significant in-field spatial variability in soil types.

Keywords: precision farming, VRT, nitrogen, corn, FEM, cropland data layer, GIS

Introduction:

Despite the intuitive appeal of precision farming, adoption of precision technology options has been well below expectations. Recent USDA Agricultural Resource Management Survey (ARMS) data indicates that only a small percentage of farmers have adopted precision nutrient and chemical applicators, while a greater portion have adopted yield monitors. A review of precision farming studies suggests as expected that precision farming becomes more profitable as in-field spatial variability increases. However, no studies have attempted to quantify infield variability at any reasonable scale beyond a few experimental fields.

To bridge this gap in our knowledge of the economics of precision farming, this study uses an innovative computer simulation approach and several widely available databases to determine relative profitability of precision nitrogen application on corn versus a uniform application rate. The approach is applied to corn production in Iowa to determine the profitability of precision corn production given the distribution of spatial attributes on corn production fields. Buchanan County in Iowa was selected for this study due to prior calibration of the computer models for that county (Keith et al., 2000; Gassman et al., 2006) and familiarity of the authors with production practices in that area.

Increased availability of spatial data on field geometry and other biophysical attributes has enabled farmers to use site-specific management methods in their production operations. Many types of harvesting equipment are now equipped with yield monitors and farmers have access to precise daily or sub-daily weather data, which allows them to determine yield responses to management and field attributes. However, precision agricultural technologies come at a cost. Many studies have shown that variable rate treatment (VRT), one of the most prominent precision farming methods, can result in improved overall farm profits that outweigh the cost of the technologies when compared to uniform application rates (Maine et al., 2010). However, specific economic comparisons depend on field-to-field and in-field variability in spatial attributes. In general, the greater the variability in field attributes across a farm, the more profitable VRT will be (Roberts et al., 2005).

A key to evaluating the relative profitability of precision farming is in linking available Geographic Information Systems (GIS) databases on field attributes to crop growth models that

predict yield responses to management as well as economic models that provide cost and returns estimates at high levels of resolution. Two computer simulation that are well suited for evaluating precision agriculture are the Agricultural Policy Environmental eXtender (APEX; Williams et al., 2000), a field-scale biophysical model, and Farm-Economic Model (FEM; Osei et al., 2000), a farm economic simulator. Both models have the capacity to simulate fields and subfields with great flexibility and detail and have been linked in previous applications. FEM and APEX have been linked in integrated modeling systems with other tools and were applied to the upper Maquoketa watershed in Iowa, which includes portions of Buchanan County. APEX is the biophysical model within the Nutrient Tracking Tool (NTT; Saleh et al., 2011), which is a USDA-NRCS tool that has farmer-friendly features and is available for use on the Internet. By linking APEX and FEM to the USDA NRCS Cropland Data Layer and high resolution soil databases, it is possible to obtain a reliable economic assessment of precision farming.

The purpose of this paper is to derive an assessment of precision nitrogen application on corn fields in Buchanan County, as an illustration of how the relative profitability of variable rate nitrogen applications can be characterized in contrast to uniform application rates. The ultimate goal is that the methodology described here can be applied to other counties and even entire states, to better characterize the economic viability of investing in precision farming technologies. While environmental indicators are also important aspects of precision farming, this paper only presents economic results.

Background and Literature Review

The potential for precision agriculture to improve farm profits has been studied extensively over the past two decades. For instance, Lambert et al. (2006) found that VRT nitrogen application

was associated with a greater profit of \$28/ha than a uniform rate of nitrogen application. Similarly, Lambert et al. (2003) concluded that VRT nitrogen applications are profitable enough to more than compensate for the added application costs. Maine et al. (2010) had a similar result in a South African study. Other studies such as Anselin et al. (2004) similarly conclude that nitrogen applications under VRT are associated with higher profit levels than uniform treatments.

Not all studies conclude that VRT is more profitable. For instance, Ruffo et al. (2006) concluded that VRT would be profitable only when the additional information required was available free. O'Neal et al. (2004) also found in their study that whole-field side dressed nitrogen applications achieved higher profits than VRT nitrogen management. Bullock et al. (2009) and Bullock (2013) contend that precision farming is not as widespread as originally anticipated because of uncertainties about yield responses to varied treatments across a farm. Consequently, farmers are unsure about whether the added cost of information and specialized application equipment would be a worthwhile investment.

A basic conclusion from the published studies is that profitability of VRT is site-specific, depending on the spatial distribution of biophysical attributes of fields on the farm. In addition, VRT is more profitable if there is greater variation in the biophysical attributes within a given field or from one field to another.

This study contributes in a significant way by showing how available GIS data layers can be used to draw inferences regarding the economic viability of precision farming tools before farmers actually invest in the technologies. By using calibrated models, the results produced from the simulations provide reasonable estimates of what can be expected on corn fields in Buchanan County, Iowa. While the present study utilizes data on biophysical attributes for corn

fields in Buchanan County, the results can be extended for the entire State of Iowa or even other states in the U.S.

Methodology

To assess the impacts of VRT nitrogen applications on farm profits and crop yields in contrast to uniform application rates, two farm optimization scenarios were evaluated as defined below. These scenarios were simulated using two computer simulation models, APEX and Farm-level Economic Model (FEM; Osei et al., 2000; Osei et al., 2012). The simulation models used, data sources, and specific optimization scenarios included are outlined presently.

Computer simulation models:

A fully linked biophysical – economic modeling system was used to determine net farm returns for each simulation. The Agricultural Policy Environmental eXtender (APEX) model was used to simulate the agronomic and biophysical impacts on a daily time step. Crop yield data estimated by APEX was passed on to the Farm-level Economic Model (FEM) for each simulation to determine the corresponding values of the economic indicators. Both APEX and FEM have been calibrated extensively and used successfully in several watersheds in Iowa. For this study, APEX and FEM were further calibrated using recent data on crop yields, nutrient losses, custom rate surveys, and farm financial performance. The calibrated models were then used in the simulations.

APEX and FEM have been linked in a previous effort to enable seamless transfer of data between the two models (Osei et al., 2008). In this study the two models were applied in a

dynamic linkage (Figure 1) to determine optimal crop production and profits under the VRT and uniform application rate scenarios. The two models were calibrated separately prior to their use in the simulations.

FEM is a whole-farm simulation model that is used to simulate farm-level economic impacts in response to alternative agricultural policy and practice scenarios. FEM operates on annual time step and can be executed for extended periods of 30 years or more. Key categories of input data required to simulate a farm in FEM include type of livestock system, manure management methods, cropping systems and cultural practices, facilities and equipment, field attributes, input and output prices, and other external factors. Economic outputs generated by FEM include total revenue, total cost, net farm returns, livestock rations, crop and livestock sales, costs of individual production components (crop and livestock enterprise costs, fertilizer expenses, labor costs, etc.), debt payment, and owner's equity (Osei et al., 2000). While FEM performs holistic farm simulations, the net farm returns values reported in this paper do not account for the added information and application costs of VRT management.

Prior to the simulations performed in this paper, FEM was calibrated against current (2013 and 2014) farm custom rates tabulated for many states in the continental U.S. Estimated costs of planting, tillage, nutrient, and chemical application operations and harvesting costs from the FEM model were all found to be consistent with corresponding custom rates data reported for recent years. A comparison of FEM output to selected custom rates data is shown in Table 1.

APEX is a modified version of the Erosion Productivity Impact Calculator (EPIC) model that has been used widely to simulate alternative management scenarios such as variations in manure and fertilizer application rates, tillage options, and adoption of other cultural and structural management practices. APEX operates on a daily time step and can be applied for a wide range

of soil, landscape, climate, crop rotation, and management practice combinations. It can be executed for a single field or used for a wide range of multi-filed configurations including whole farms or small watersheds. APEX is detailed enough to simulate precise management practices such as filter strip impacts on nutrients losses from waste application fields. The main APEX components are weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, tillage, management practices, crop management and growth, and pesticide and nutrient fate and transport. Choice of simulated cropping system, manure and/or fertilizer nutrient characteristics, tillage practices, soil layer properties, and other characteristics are input for each simulated subarea. Key outputs include crop yields, edge-of-field nutrient and sediment losses, and other water and nutrient balance indicators.

APEX was calibrated against annual county-level crop yield data assembled by the USDA National Agricultural Statistics Service (USDA-NASS) and available on the USDA-NASS web site. The model is included in NTT and has been calibrated extensively by many other authors for use to assess edge-of-field water quality impacts across a wide variety of agricultural lands in the U.S. and other nations (Gassman et al., 2010).

Data Sources:

A number of data sources were used for this study. Many of the following datasets are incorporated into the web-based NTT tool. Others were assembled specifically for this study. As described below, various Geographic Information Systems (GIS) data layers were overlaid in order to determine the distribution of corn growing areas in Buchanan County, Iowa.

Cropland data layer (CDL): A four-year GIS history of cropland cover for the entire United States was obtained from the USDA-NRCS data server. The cropland data used for this study

covered the time period of 2010 through 2014. The CDL data is available at a 30-meter level of precision. The data layer for Buchanan County, Iowa for 2014 includes tens of thousands of field polygons that reflect the distribution of corn fields in the County. While these field boundaries do not represent the size of farmlands, they do represent approximate corn field dimensions in 2014.

SSURGO soils data: The USDA-NRCS SSURGO soils data for each survey area of the United States have also been assembled. For this study, the SSURGO data layer was overlaid on the CDL data in order to determine the soil types applicable to corn production fields in Buchanan County, Iowa. The overlay of SSURGO soils data on the CDL crop cover produced over 164,000 polygons or subareas representing field-soil type combinations where corn is grown in Buchanan County, Iowa. The distribution of corn field-soil type polygons by size is shown in Table 2. These polygons would represent site-specific management zones, the boundaries of subfields that are candidates for precision targeted management practices to maximize farm profits.

For the present study, the number of polygons was considered too numerous for our purposes. A large number of the polygons were less than one acre in size. For this paper, only polygons of size 10 acres or larger were considered. Further study will be performed to include polygons down to one acre in size.

Weather data: Precipitation, minimum and maximum temperature, solar radiation, and other key weather variables were obtained from the USDA Parameter-elevation Regressions on Independent Slopes Model (PRISM) database. The weather data are also available on the NTT server and were used for the present simulations. The PRISM data used for this study are available at a 4-kilometer resolution for the continental U.S. The simulations presented here were

performed with a 47-year history of weather data from 1960 through 2006 to adequately reflect typical weather patterns in Buchanan County, Iowa.

Corn management: Typical corn cultural practices for Buchanan County, Iowa, were obtained from the USDA NRCS crop management zones (CMZs) applicable to northeast Iowa. For simplicity of the present study, only one corn management was used for all soils. A corn management including spring tillage was chosen for the simulations. The specific list of field operations included in this management file is provided in Table 3. The corn management file was converted into APEX and FEM formats for the model simulations. The same dates and field operations were used for all soils. The only parameter that varied in all simulations was the rate of nitrogen application; no other management information was changed. In addition to the operations specified in Table 3, the APEX simulations included a “kill” operation that terminated the growth of the corn crop one day after each year’s harvest operation. FEM also included various post-harvest operations such as drying, handling, and marketing. Finally, it is important to note that the management information contains no irrigation. The present study was performed to reflect dryland corn grain production in northeast Iowa.

Price and other economic data: The corn price used for the simulations was the average of the most recent five years of annual average corn price (2010 through 2014), obtained from the USDA Agricultural Prices Summary database. Fertilizer prices were also based upon the most recent five year average price. Equipment prices were based on current retail prices of the same types of field implement, tractors and combines. Labor wages, interest rates and other borrowing terms were also based on recent averages published by USDA and lending institutions. Finally, a

500-acre representative farm was used in all economic simulations to determine the farm economic implications of the alternative VRT and uniform rate scenarios.

Precision and uniform nitrogen rate scenarios:

To evaluate the implications of VRT management as compared to uniform treatments, two scenarios were simulated across all soils. A 47-year time horizon was used for each scenario in both APEX and FEM. For each simulation and for all scenarios, a phosphorus application rate of 25 lb/acre was used regardless of soil phosphorus levels.

Precision profit maximizing nitrogen rate: The variable rate nitrogen application that maximizes farm profits was obtained for each field-soil type polygon by iteratively simulating APEX and FEM and using optimization algorithms to determine the nitrogen rate that resulted in maximum profit for each polygon. The resulting nitrogen rate was used in both APEX and FEM to determine the corresponding crop yield and farm profits.

Uniform profit maximizing nitrogen rate: The uniform profit maximizing rate was obtained as follows. The variable rate profit maximizing nitrogen rate scenario was first simulated. Then the nitrogen rates that maximized profit for each field-soil type were averaged across all soils types for the given field to obtain the uniform profit maximizing rate for that field. Thus, given the profit maximizing rate $r_i^{\pi_{max}}$ for a specific soil type i , the uniform profit max rate for the field was computed as the mean equivalent rate $\bar{r}^{\pi_{max}} = \sum_{i=1}^n r_i^{\pi_{max}} / n$.

Thus, for each field-soil type polygon, two scenarios were simulated. First, a profit maximizing rate of nitrogen application was determined using an optimization procedure involving the biophysical and economic models. Next, an average of the profit maximizing nitrogen application rate for each field was applied as the uniform nitrogen application rate across all soil

types relevant for that field. The relative profitability of precision farming was determined by comparing the net farm returns of the profit maximizing precision nitrogen applications scenario with the net farm returns corresponding to the uniform rate.

Limitations of the Study:

A key limitation of this study is that we did not incorporate the additional cost of VRT applications in the economic evaluations. Consequently, the increased profits reported here are best described as margins representing the increased revenue over variable costs of purchased fertilizer under VRT as compared to the uniform application rate scenario. Thus VRT would be considered viable if these margins exceed the additional application and management costs; otherwise, VRT would not be viable.

Another limitation is that the only management practice altered was nitrogen application rates. Consequently, only a limited opportunity was included in this study to reveal the full advantage of VRT technologies. Finally, not all field-soil type polygons were simulated. While the larger polygons were included (a total of over 50 percent of all corn fields in the county), a significant percentage was not included and might have introduced enough spatial variability to alter the conclusions of the study.

Results and Implications:

The results reported here show that viability of VRT effects depends on the number of soil types per field. VRT profits excluding additional application costs, were on average about \$4.78/acre. The profit margin resulting from VRT is indicated to depend to some degree on the number of

soil types for a given field (number of site specific management zones). As expected, there is no profit gain if the entire field is represented by one soil. In such cases, assuming that the soil type distribution completely represents all relevant variations in spatial attributes for each field, there is no benefit to adopting VRT nitrogen applications. While the margin is rather small (mostly less than \$10 per acre) VRT nitrogen applications entail improved and somewhat increasing profit margins, as the number of site specific zones within a field increases (Figure 2).

However, using the standard deviation in soil slopes as a measure of in-field variability, profit margins are not indicated to increase as the variability of soil slopes within a field also increases. In general, this is attributable to the fact that there was not a significant diversity in slopes across the soils in a given field. Slope values varied mostly from less than 1% to almost 8%. Thus there does not appear to be a significant range in soil slopes to affect yields and hence net incomes when site specific management zones are delineated within a field.

Conclusions:

Results of the simulations indicate that profitability of precision farming may correlated with in-field spatial variability, but only marginally so. Spatial variability in soil slope – a key soil attribute impacting crop yields and farm profitability did not reveal any significant pattern. Additional analysis will be performed with soil physical and chemical attributes to further determine any correlation between their variability and the profitability of precision nitrogen applications on corn. The method introduced in this paper can be applied to other counties and states to determine the potential for VRT and other precision farming technologies.

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TABLES:

<i>Field operation</i>	<i>Custom rate</i>	<i>FEM Model Output</i>	
		<i>Fixed Cost</i>	<i>Total</i>
Moldboard plow	18.68	13.37	19.79
Tandem Disk	13.46	7.36	15.13
Chisel Plow	14.32	7.35	16.33
Field Cultivator	11.36	2.88	11.76
Offset Disk	14.4	5.96	16.23
Rotary Hoe	7.56	4.89	8.06
Row Crop Cultivator	10.42	4.99	11.68
Bulk Fertilizer Spreader	6.61	1.14	5.69

Table 2: Size distribution of field-soil type polygons

Size range of polygon	Frequency	Contributing Area	
		Acres	Percentage
< 0.5 acres	97,690	16,247.7	4.4
0.5 to 1 acres	18,879	13,647.4	3.7
1 to 5 acres	33,656	76,922.5	21.0
5 to 10 acres	7,256	50,521.5	13.8
10 to 20 acres	3,917	54,634.1	14.9
> 20 acres	3,314	154,438.9	42.1
Total (All Polygons)	164,712	366,412.1	100.0

Table 3. Field operations simulated for continuous corn

Date	Operation	Application Type
February 1	Tandem disk	
April 21	Fertilizer / Nitrogen	Surface
April 21	Fertilizer / Phosphorus	Surface
April 21	Planting Corn	
May 21	Disk	-
June 21	Disk	-
October 21	Harvest corn	-

FIGURES:

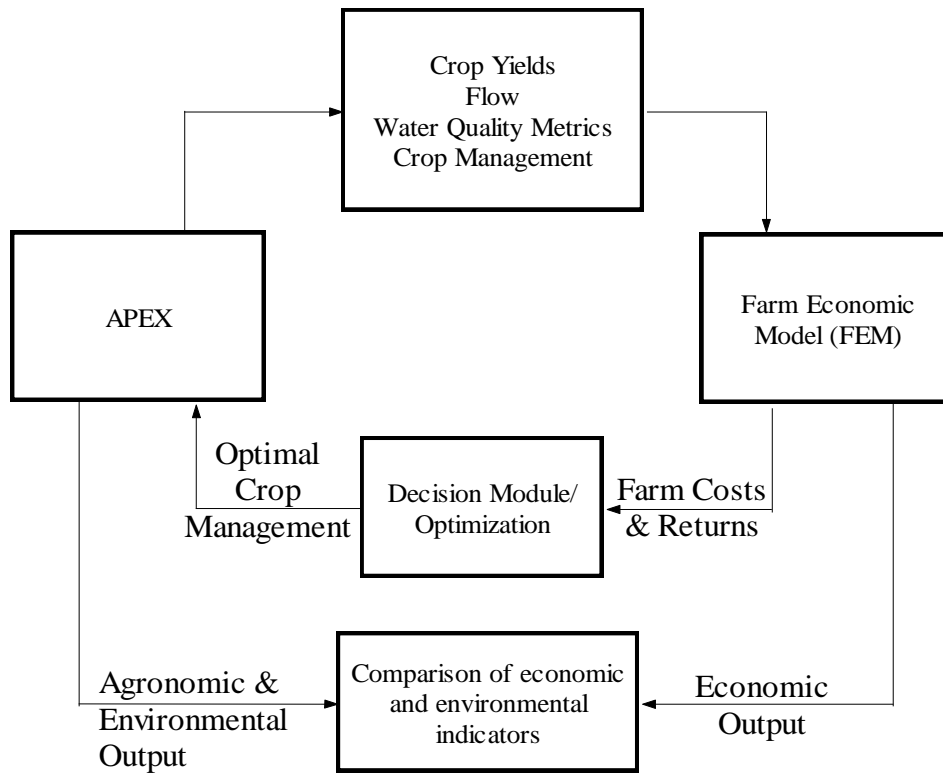


Figure 1. Schematic of FEM and APEX linkage for scenario simulation and analysis

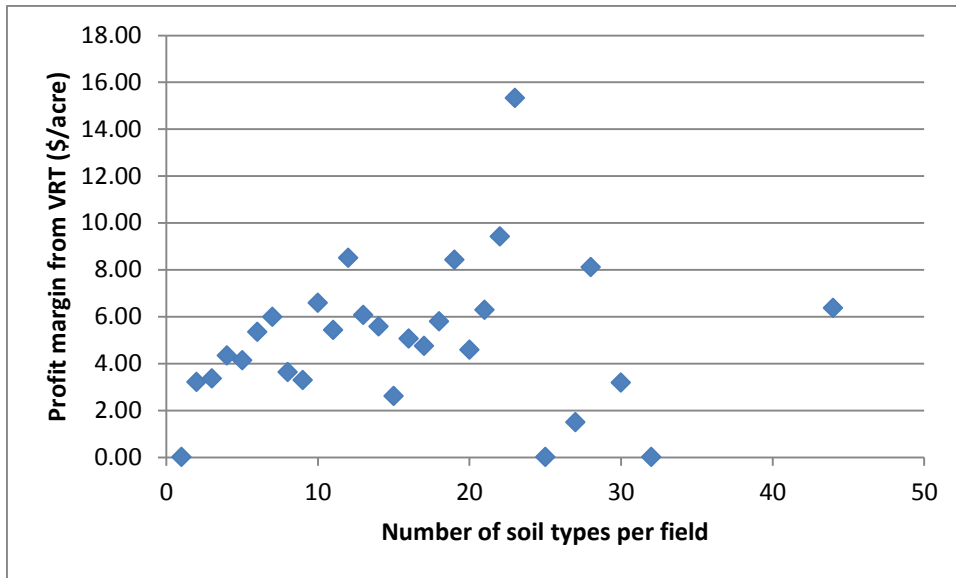


Figure 2. Correspondence between VRT profit margin and number of soil types within a field.

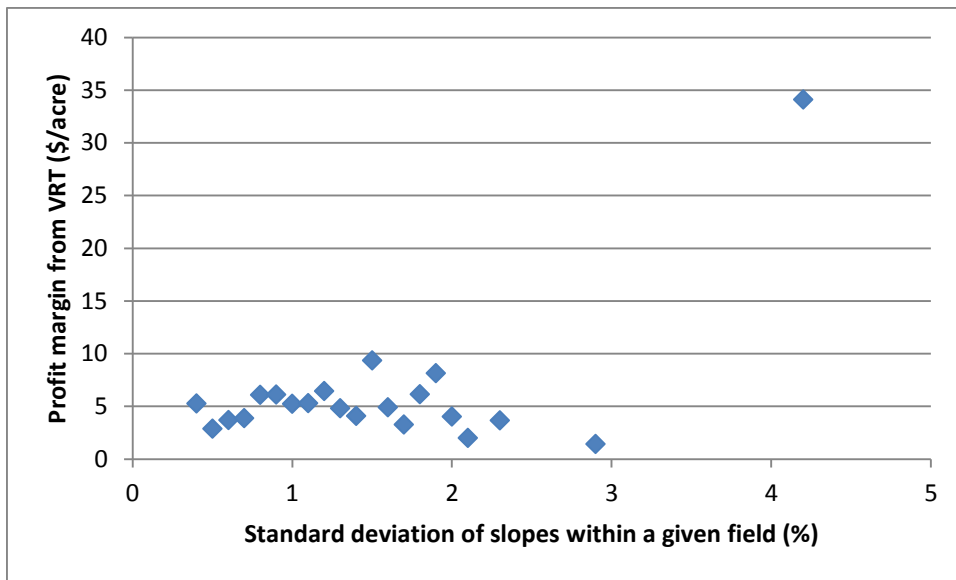


Figure 3. VRT profit margin corresponding to variability of soil slopes within a field