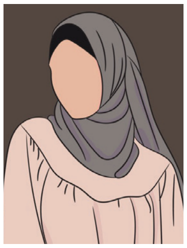
Returns to Zone Management Under Varying Conditions



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Abstract

A framework for individual-farmer evaluation of the net benefits of adopting precision agricultural technologies was developed and tested. Partial budgeting analysis was used to calculate the net profit effect of adopting precision agriculture technology bundles on three farms differing in input use and location. @Risk was used to account for risk. Results show that adopting zone application of fertilizers and seed can be profitable for farms with moderately variable soils and this is amplified with higher prices, but that adoption of zone application may not be profitable for farms with low input use variation such as those irrigated.

INTRODUCTION

Precision Agriculture Technologies (PAT) refers to a set of technologies designed to reduce input costs or optimize field management practices and yield by providing farmers with detailed spatial information (National Research Council, 1997). PAT include grid/zone soil mapping, guidance systems, yield monitoring (YM), yield mapping (Ymap) with Global Positioning System (GPS)/Global Navigation Satellite System (GNSS),[1] unmanned aerial vehicle (UAV)/drone imagery, and variable-rate technology (VRT) input application.

PAT have gained increased importance in the agricultural industry over the past two decades. For major U.S. field crops, guidance systems have been adopted for 40% to 60% of planted acres, GPS soil mapping for 15% to 25%, and VRT fertilization for 10% to 30% (Schimmelpfennig and Lowenberg-DeBoer, 2020). Dealers report that their availability of precision agriculture (PA) service offerings increased drastically from 2008 to 2019 and again from 2019 to 2021 (Erickson and Lowenberg-DeBoer, 2021). Eighty-eight percent of dealers report offering grid or zone soil sampling and VRT fertilizer application, and 44% offer UAV/drone imagery.

PA manages yield potential and within-field variability caused by heterogeneity in soil physiochemical properties. It can contribute to the long-term sustainability of agriculture through more tailored input applications that reduce losses from excess applications and due to nutrient imbalances (Carrer et al., 2022; Finco et al., 2021; Kolady and Van Der Sluis, 2021; Nawar et al., 2017). PAT have particular potential where input costs are high, inputs are applied at variable rates, high value crops are grown, field variability is high, and environmental deterioration needs to be mitigated (Van Evert et al., 2017). However, the benefits of PA depend on many factors such as region, type of crops grown, soil variability, and farm size (DeLay and Comstock, 2021; Van Evert et al., 2017; Schimmelpfennig and Lowenberg-DeBoer, 2020). Thus, although there is interest among farmers in using PAT (Carrer et al., 2022; Van Evert et al., 2017), many farmers are yet to be convinced of their profitability for their own operations.

Economics of PA

The results of previous research considering the economics of adopting PAT have been mixed. Schimmelpfennig (2016) reported that the adoption of GPS soil and Ymap, guidance systems, or VRT led to a positive but small increase (1.1% to 2.8%) in net return and operating profits for corn. Schimmelpfennig (2018) found similar results with a small increase (1.1% to 1.8%) in operating profit for soybeans. Dhoubhadel (2020) found that PAT-adopting farms had higher returns than non-adopters and that variability of net returns was higher for non-adopters than for farms having adopted two or more technologies. He found that grid soil sampling technology helped farms increase net returns by an average of $53 per acre over farms with no PAT and that any combination of technologies that includes grid soil sampling can positively contribute to the net returns of the farm. Schimmelpfennig and Ebel (2016) found that most PAT combinations, including YM, Ymap, GPS, soil sampling, and guidance systems, show some cost savings. The largest average variable costs savings ($25 per acre) was found from the combination of YM and Ymap. Adding VRT to this combination did not bring any further cost reduction, which validates its lower adoption rate. However, adding VRT with soil mapping and YM brought additional cost reductions of $13 to $21 per acre. Schimmelpfennig and Ebel (2016) hypothesized that the inconsistency in cost savings associated with VRT is because it may result in increased input costs in some cases where increased input use can lead to an increase in output and profits.

Overall, existing literature suggests that the benefits of PAT can be very farm specific and vary significantly based on farm size (Dhoubhadel, 2020; Van Evert et al., 2017; Finco et al., 2021; Schimmelpfennig and Lowenberg-DeBoer, 2020), region (Schimmelpfennig and Lowenberg-DeBoer, 2020), type of crops grown (Dhoubhadel, 2020; Schimmelpfennig and Lowenberg-DeBoer, 2020), soil variability (Finco et al., 2021; Schimmelpfennig and Lowenberg-DeBoer, 2020; Srinivasan, Shashikumar, and Singh, 2022), and uncertainty about output and input prices (Finco et al., 2021). However, most research efforts have been generalized across farms and, as such, do not provide individual farmers with a clear understanding of the potential profitability of PAT for use on their unique farms. More research is needed on the economic viability of PA based on soil variability and other farm characteristics so that farmers can make informed choices about its adoption. We look at the effect of adopting a PAT bundle (soil sampling, zone mapping, and VRT) on the profitability of three farms and develop a model to calculate profitability that can be applied to individual farm situations.

METHODS

Our primary goal was to develop a model to help farmers estimate net benefits for their unique farms. A partial budgeting model was developed in Microsoft Excel. The process measures net benefits of a project starting with benefits realized (additional revenues or cost savings) and subtracts additional expenses. In our model, the net benefit of adopting a PAT bundle including soil sampling, zone mapping, and variable rate seed and fertilizer application is assessed. We consider profits on three case farms with and without adoption.

Our analysis assumes that yield goals are similar whether the farmer is adopting the PAT bundle or not, and that yield goal is not dependent on input cost or output price. This is consistent with regional farmer decision-making. Farmers generally plant to maintain or improve on their current yields and to maintain their actual production history yields. Federally subsidized crop insurance provides some incentive to apply inputs for yields on marginal acres above that which an economist might recommend. With a similar yield goal under traditional production and employing the PAT bundle, the focus is on the difference in input costs. Output price and input cost risk were added to the analysis using @Risk.

DATA

Revenues and costs that differ between adopters and non-adopters are included in the model. The primary cost difference is due to variable inputs of fertilizers and seed. Other costs differing between the scenarios are soil sampling, zone mapping, fertilizer recommendation, dry fertilizer application, and a hydraulic pump. Input use and yield data for the example farms come from three corn farms, one farm each in Richland County (North Dakota), Barnes County (North Dakota), and Boone County (eastern Nebraska) (Table 1; Figure 1). The PAT scenarios are estimated using yield goals, seeding rates, and fertilizer application rates for these three farms provided by Agveris in Casselton, North Dakota. The National Agriculture Imagery Program (NAIP) and Normalized Difference Vegetation Index (NDVI) imagery along with yield data are used to create five management zones for each field. Each management zone is then soil sampled after harvest, and those results are used to provide fertilizer and seed recommendations. The non-adoption scenarios assume traditional and field-common yields and application rates for inputs.

Table 2 shows a sample fertilizer recommendation. The first column lists the yield goals and names of inputs differing due to zone management. The last column shows the traditional rate of applications used before adopting PA. In most cases, yield goals are similar for both PA and traditional fields, but input recommendations are lower for PA. Other costs that differ are shown in Table 3.

In addition to a static analysis, for which December 2020 prices are used, @Risk is used to develop cost and price distributions to estimate the expected range of changes in net return from PAT adoption. For the latter, historical monthly prices of corn and fertilizers (except sulfur) are collected from the DTN ProphetX application. The historical monthly North Dakota price series from 2010 to 2020 was used for corn, nitrogen (urea), phosphorus (MAP),[2] potash, pop-up (10-34-0), and UAN[3] 28. The yearly price series of sulfur from 2010 to 2022 is used (Ron Haugen, Personal communication, May 10, 2022) due to unavailability of monthly prices. Corn seed price data is collected from annual North Dakota State University crop budgets. Excluded from the analysis are 2021 and 2022 prices because price of corn and all fertilizers started to increase sharply from 2021.

RESULTS

The objective was to identify the differential profit per acre between adopters and non-adopters of VRT under different price scenarios and considering price and input cost risk. Reported are static results, sensitivity analysis, and risk analysis.

Static Results

Table 4 shows static annual net profit results using prices from December 2020, when prices began to increase substantially associated with trade policy and COVID-19–related anomalies. Differential profit per acre—defined as profit under PAT adoption less profit under non-adoption—is $23 for ND1, whereas it is $13 for ND2. This was unexpected because of the higher soil variability on ND2. Economic theory indicates that the benefits of PAT adoption increase with variability in soil productivity. Here, there was a slight difference in yield goal between the PA and traditional scenarios of both farms. ND1's PA yield goal is slightly higher than the traditional rate and ND2's PA yield goal is slightly lower. The higher yield goal for the PA scenario in ND1 brings additional revenue, increasing the differential profit per acre for ND1.

Sensitivity Analysis

Sensitivity analysis calculates net profit differential using June 2022 prices to compare the change in profits when prices have almost doubled (Table 5). When prices increase, the profits of farms adopting the PAT bundle increase more than those not adopting. This was expected because the benefit of reduced input use under PAT grows with higher-priced inputs.

Figure 2 shows this graphically, demonstrating sensitivity of profits to changes in prices. Depicted are the three case farms. The base point uses December 2020 prices.

The horizontal axis shows the assumed increase in prices. Differential profits for ND1, ND2, and NE in the base case were $23, $13, and –$4 per acre, respectively. When prices were increased by 100%, which is slightly less than 2022 prices, the profit differentials almost doubled. Among all three farms, the rate of increase in differential profits with respect to increases in prices is the highest for ND2. This farm is using some of the more expensive fertilizers. The reduced cost associated with ND2 applying less fertilizer is therefore greater under higher fertilizer prices. Ultimately, higher per unit costs of inputs variable rate applied leads to an increase in profits associated with using PA for ND2 as compared to the other case farms, leading to convergence of the profit differential.

Risk Analysis

The Monte Carlo simulation feature in @Risk simulation was used to develop profit distributions. For the static analysis, December 2020 prices were used. But for the @Risk simulation, price series from 2010 to 2020 were used.

ND1 can earn a minimum differential profit of $26 per acre and a maximum of $66 per acre. The mean is $30 per acre. There is a 90% probability that the differential profit will be between $27 and $35 per acre (Figure 3), which is much higher than our static results. It is evident that adopting PA is highly profitable for ND1, not only under a higher price but also in a historic market environment.

The range of differential profit for ND2 is between $10 and $29 per acre. The average is $13 per acre. There is a 90% probability that the differential profit will be between $11 and $16 per acre, which is a little higher than the average static results (Figure 4). So, adopting PA for ND2 is moderately profitable in a normal market environment.

NE can earn a minimum differential profit of –$3 per acre and a maximum of $4 per acre. The mean is –$2 per acre. There is a 90% probability that the differential profit per acre will be between –$3 and $0 per acre, which is higher than our static results (Figure 5). NE was an irrigated field, and they applied some fertilizer through irrigation to all zones at a flat rate. Fertilizer recommendations were only slightly different between PA and the traditional scenarios.

CONCLUSIONS AND RECOMMENDATIONS

The primary goal of this research was to build a model that farmers can use to calculate the net benefits of adopting PAT based on their unique farm characteristics. Our hypotheses were that adoption of PA would increase net profit and that an increase in prices would result in a larger differential profit between farms adopting PA and those not because applying fewer inputs will lead to a greater savings in input costs under higher prices.

Results support the hypothesis that a bundle of PAT including soil sampling, zone mapping, and VRT can be moderately to highly profitable for farms that are variable in terms of soil fertility. Typically, the more variable the field, the higher the increased differential. Exceptions occur when other revenues or costs are affected, as was the case here when ND1 benefited more from adoption of PA than the more variable ND2 because yield goal slightly increased for ND1 and slightly decreased for ND2 with adoption. For farms with little variability in soil productivity or conditions that do not accommodate more than minimal input application variability, adoption of this PAT bundle may not be economically viable. Supporting the second hypothesis, sensitivity analysis shows that differential profit per acre increases significantly with an increase in prices.

Recommendations

The PAT bundle (soil sampling, zone mapping, VRT) considered for this research can be suggested to farmers who have a variable field in terms of soil productivity, noting that more field variability should increase the differential profit per acre of the farm above operating without the PAT bundle. It is important that farmers estimate and use their own soil variability information, prices, and costs associated with adopting PAT in estimating the potential for their farm operation and consider not just current crop and price levels but those forecast over time. To circumvent a focus on the importance of intermediate to long-term price forecasting accuracy, a farmer can custom hire PA operations if current and short-term market forecasts support this. Although adopting PA may be profitable for non-irrigating farms, a traditional rate of input application may be more appropriate for irrigated farms due to the lack of variability in the input application rate over the field.

Challenges and Directions for Future Research

Even though the potential benefits of PA are widely recognized, many farmers remain uncertain about how it will affect their profits. Investment in PAT is therefore hindered. Challenges for farmers include increased application or management costs, investment in new equipment, training of employees for technology use, and uncertainty (Finco et al., 2021; Schimmelpfennig, 2016). Unless custom hired, adoption of PAT increases expenditures on machinery and equipment due to the capital-intensive nature of these technologies. This may in part explain why larger farms that can spread capital expenditures across more acres adopt PAT at a faster rate than smaller farms. Farm implements with VRT capabilities in particular have a relatively high capital cost and require additional operator time. Therefore, many producers have chosen to hire service providers when selecting VRT, particularly in smaller operations (Schimmelpfennig, 2016). Concerns over data privacy and security may also constrain adoption (Idowu, 2022).

Future studies on the profitability of adopting PAT can be done with a large dataset and varied types of fields that have adopted PA on their farms. Taking sample farms from different states and including farms producing different types of crops would also shed additional light. More research investigating the impact of soil variability and differing PAT bundles on the profitability of farms adopting PAT would also be of value.

FOOTNOTES

1. GNSS is formerly referred to as GPS. The main distinction between GPS and GNSS is that GNSS provides global coverage. Although these terms can be used interchangeably, GNSS is used worldwide. Most of the recent research on PA uses GNSS instead of GPS.
2. Monoammonium Phosphate is referred to as MAP.
3. Urea Ammonium Nitrate is referred to as UAN.

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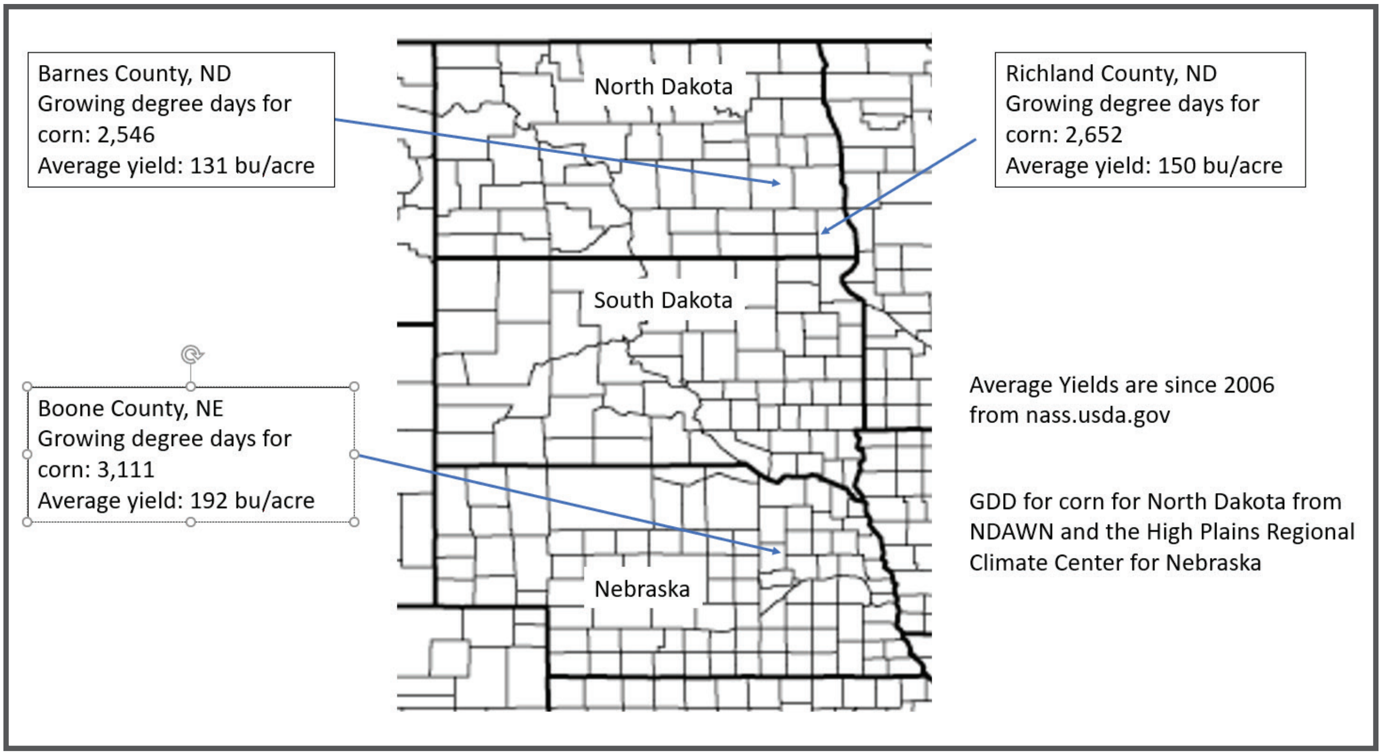

Figure 1. Case farms

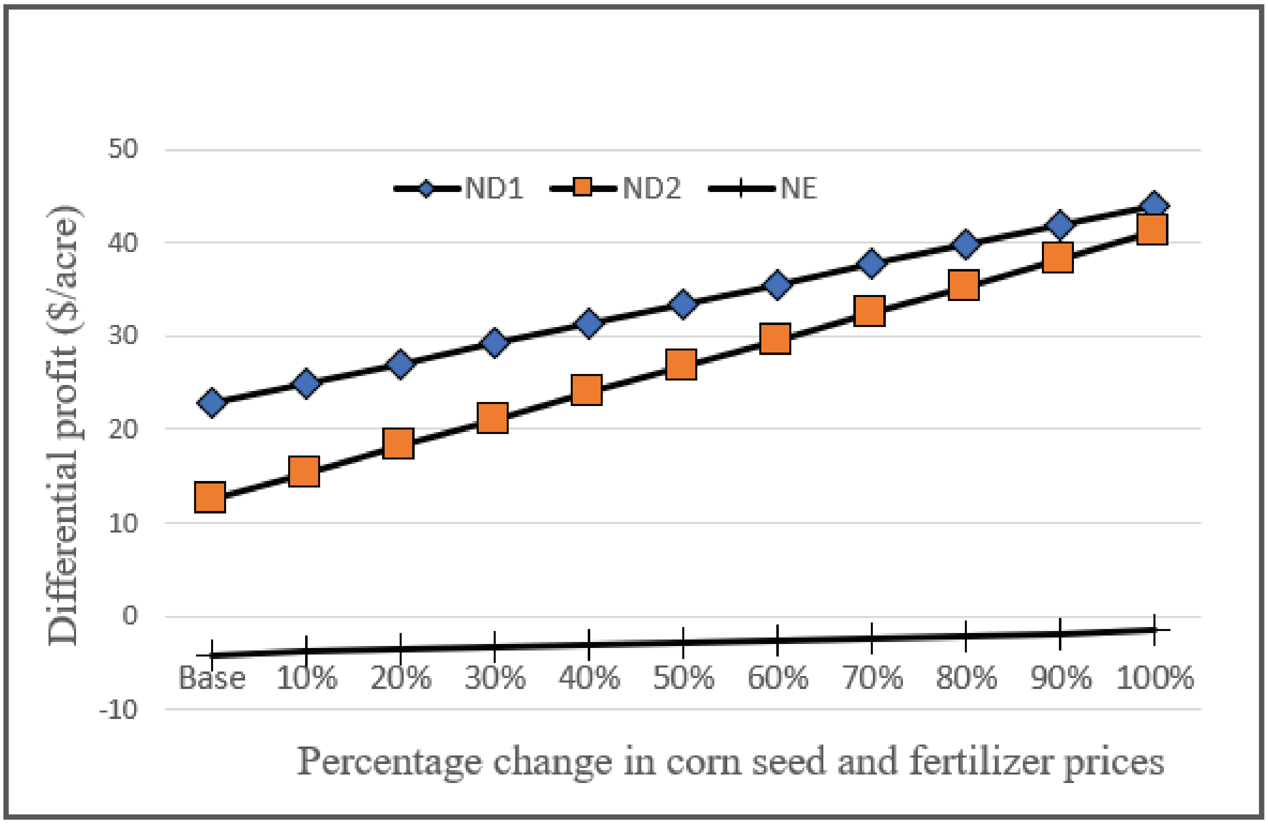

Figure 2. Sensitivity of differential profits to price changes

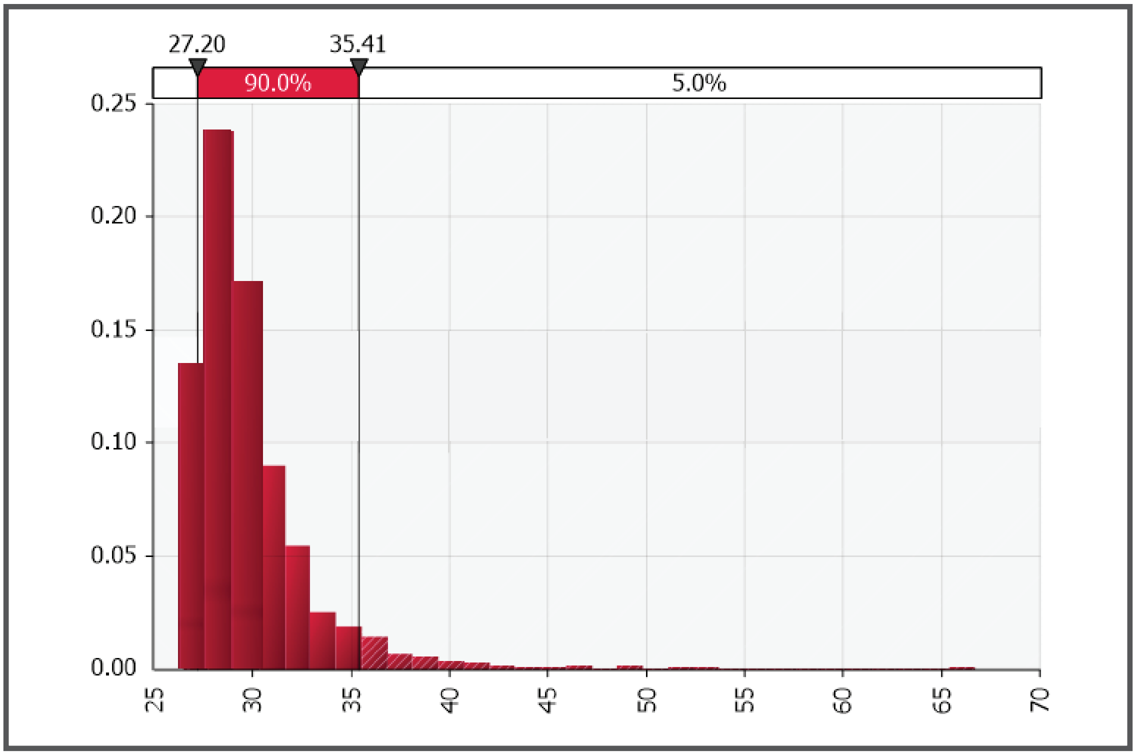

Figure 3. Differential profit ($/acre) for ND1

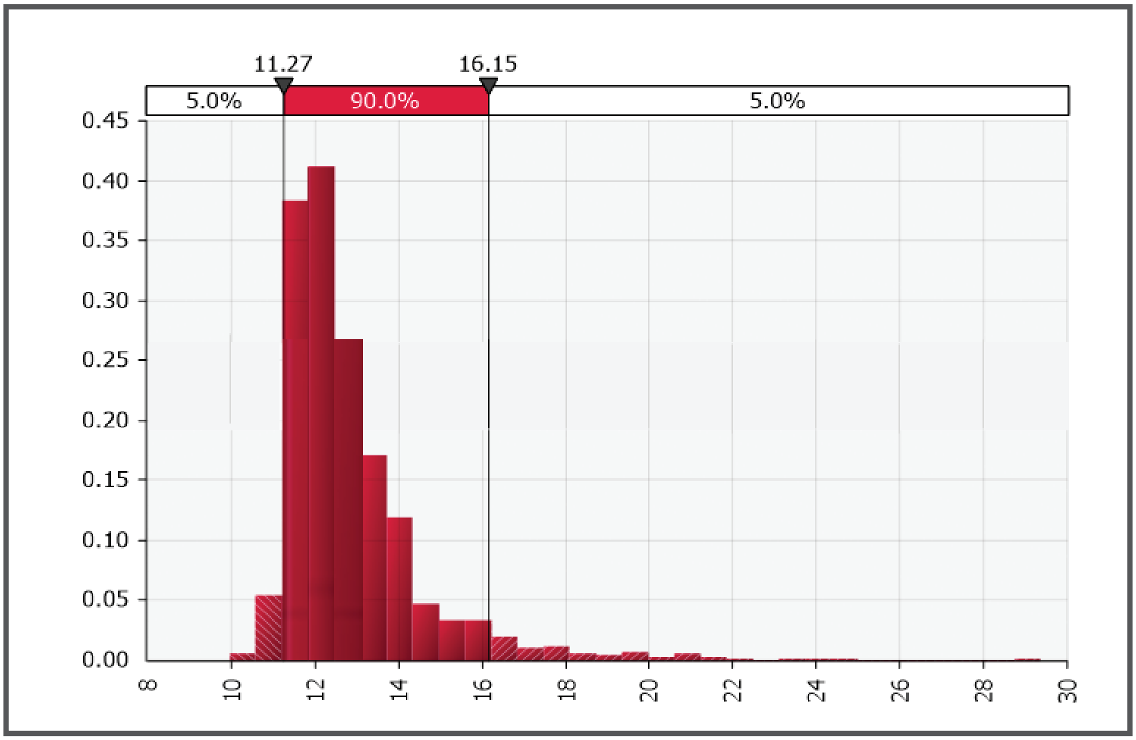

Figure 4. Differential profit ($/acre) for ND2

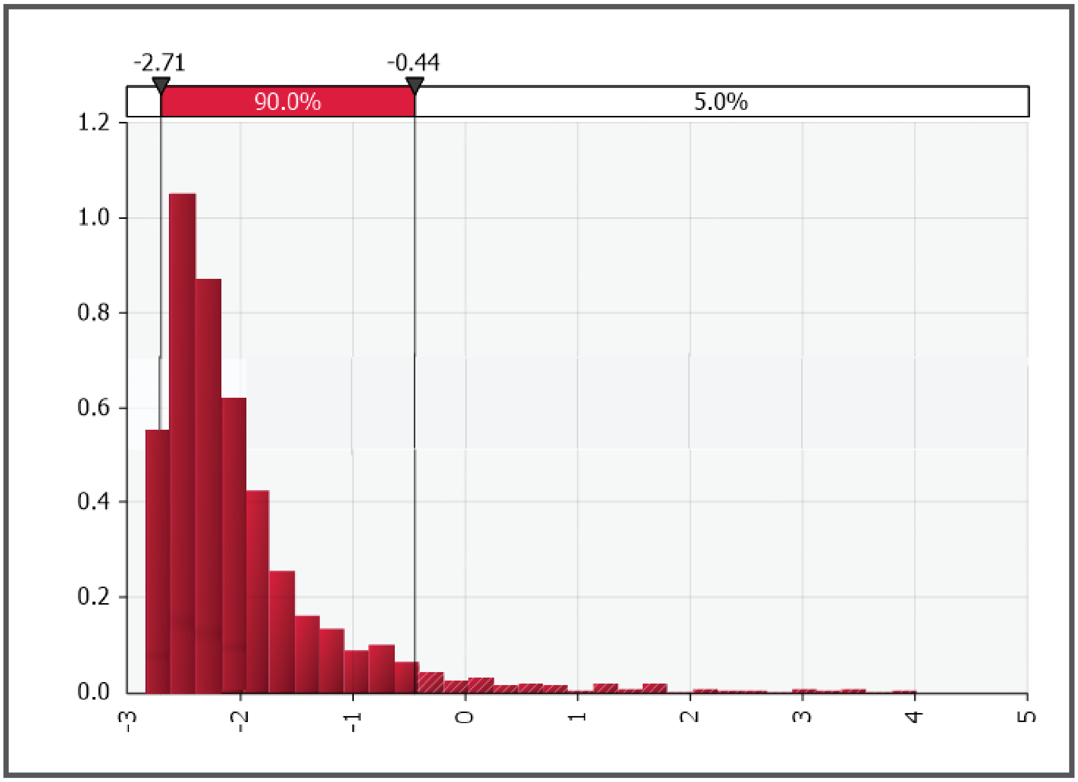

Figure 5. Differential profit ($/acre) for NE

Table 1. Case Farm Characteristics

Farm	Location	Size (acres)	Irrigation Type	Soil Variability
ND1	Richland County, ND (South Valley Region)	158	Non-irrigated	Little to no soil variability, flat
ND2	Barnes County, ND (Southeast Region)	161	Non-irrigated	Significant soil variability, moderate slope
NE	Boone County, Eastern Nebraska	125	Irrigated	Moderate soil variability, flat

Table 2. Sample Corn Input Recommendations by Zones[a]

Value/Zones	1	2	3	4	5	Weighted Average	Traditional
Yield Goal (bushels)	120	150	160	180	200	189	185
Seeding Rate (1000)	24	27	29	31	35	31.6	32
Nitrogen, Urea	195	215	268	270	295	271	325
Phosphorus, MAP	0	19	50	100	140	102	100
Potassium-Potash	0	0	70	74	75	65	100
Sulfur, AMS	20	47	51	60	66	58	75
Pop-up Fertilizer 6-24-6 (gallons)	3.0	3.0	4.5	4.5	5.0	4	5.0

[a] Unless indicated, input use is noted in pounds.

Table 3. Cost Differences Between PA and Traditional Rate ($/acre)

Costs	PA Rate	Traditional Rate
Soil Sampling	2.5	1.25
Zone Mapping	3	–
Fertilizer Recommendation	6	–
Dry Fertilizer Application	10	8
Hydraulic Pump	1	–

Table 4. Static Results[a]

	ND1		ND2		NE	
	PA	Traditional	PA	Traditional	PA	Traditional
Revenues						
Revenue from Corn	633.38	619.75	545.65	552.75	892.84	887.75
Costs						
Nitrogen (Urea ND, 28% NE)	49.73	59.64	44.22	50.46	86.30	89.20
Seed	94.92	96.00	92.12	96.00	106.62	108.00
Phosphorus (MAP)	27.39	26.85	25.78	33.56	0.00	0.00
Potassium (Potash)	11.90	18.30	0.55	9.15	0.00	0.00
Sulfur (AMS)	9.43	12.19	8.94	12.19	0.00	0.00
Pop-up Fertilizer	10.76	13.46	10.76	13.46	13.81	13.46
Dry Fertilizer Application	10.00	8.00	10.00	8.00	10.00	8.00
Soil Sampling	2.50	1.25	2.50	1.25	2.50	1.25
Hydraulic Pump	1.00		1.00		1.00	
Fertilizer Recommendation	6.00		6.00		6.00	
Zone Map	3.00		3.00		3.00	
Total Differential Costs	226.62	235.68	204.87	224.07	229.23	219.91
Returns	406.76	384.07	340.77	328.68	663.61	667.84
Differential Return	22.70		12.09		–4.23	

[a] All numbers are reported in $/acre. Returns are to labor, management, fixed costs, and variable costs that are not different between systems. These variable costs include herbicides, crop insurance, fuel and lubrication, repairs, drying, and operating interest. Fixed costs include machinery investment and depreciation, land charge, and miscellaneous overhead.

Table 5. Sensitivity Analysis of Profits and Differential Profits

Differential Profit, $/acre[a]	ND1	ND2	NE
June 2022 Prices	52	38	3
December 2020 Prices	23	13	–4

[a] Profit per acre is the return to fixed costs, management, and input costs except those noted as different between the adoption and non-adoption scenarios.