Journal of Agricultural and Applied Economics, 43,1(February 2011):57–75
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A Whole Farm Analysis of the Influence of Auto-Steer Navigation on Net Returns, Risk, and Production Practices

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A whole farm economic analysis was conducted to provide a detailed assessment into the economic, risk, and production implications due to the adoption of auto-steer navigation. It was determined that auto-steer navigation was profitable for a grain farmer in Kentucky with net returns increasing up to 0.90% ($3.35/acre). Additionally, the technology could be used in reducing production risk. Adoption of the technology also alters production practices for optimal use.

Key Words: economics, farm management, mean-variance, precision agriculture, simulation

JEL Classifications: C61, C63, D81, Q12, Q16

Automated steering (auto-steer) is a navigation aid that utilizes the global position system (GPS) to guide agricultural equipment. Auto-steer has been commercially available for many years. There are many combinations of auto-steer systems and GPS receivers available with correspondingly different levels of accuracy. The potential benefits of these systems include reduction of overlaps and skips, reduced inward drift of implements, the lengthening of operator's workday, accurate placement of inputs, and reduced machinery costs resulting from an increase in machinery field capacity. The increase in machinery field capacity not only could reduce direct costs, but permit more land area to be planted closer to the optimal date. These advantages provide incentive for producers to evaluate the potential of this technology in their farm operation.

Many Kentucky farmers have adopted some form of GPS-enabled navigation technology. The trend for most Kentucky farmers is to first adopt a bolt-on auto-steer system equipped with a sub-meter receiver on the self-propelled sprayer. For the utmost accuracy, a Kentucky farmer upgrades to an integral valve system with a Real Time Kinematic (RTK) GPS receiver on the tractor. Few Kentucky farmers have utilized auto-steer systems on their harvesters, but when they do, it is common to use a bolt-on system. Despite rapid adoption, the quantitative benefits of auto-steer have been

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The authors would like to thank the editor and the three anonymous reviewers for their helpful comments. This research was partially funded by a U.S. Department of Agriculture-Cooperative State Research, Education, and Extension Service Grant titled "Precision Agriculture: Development and Assessment of Integrated Practices for Kentucky Producers" and was supported by the University of Kentucky Agricultural Experiment Station. It is published by permission of the Director as station manuscript number 10-04-110. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the U.S. Department of Agriculture.

scrutinized by farmers. A thorough investigation by researchers into this technology is long overdue. Issues regarding profitability, interactive effects of production practices, and the often ignored issue of risk are all essential to evaluate.

The majority of existing studies conducted on navigational technologies focused on field performance or general overviews of the technology, which ultimately emphasized engineering concepts. Field performance studies focused on issues regarding accuracy, topography, speed, and evaluation methods (Ehsani, Sullivan, and Walker, 2002; Gan-Mor, Clark, and Upchurch, 2007; Stombaugh et al., 2007; Stombaugh and Shearer, 2001). Research involving the overall status of navigational technologies in North America and Europe had also been reported (Adamchuk, Stombaugh, and Price, 2008; Keicher and Seufert, 2000; Reid et al., 2000). Other research previously conducted had focused on the economics of auto-steer.

Economic studies regarding auto-steer often utilized simple techniques which failed to encompass all benefits and costs of the technology. A limited number of whole farm economic studies of auto-steer had been conducted (Griffin, Lambert, and Lowenberg-DeBoer, 2005, 2008). These economic studies had not included a farm manager's ability to exploit the technology by altering production practices to increase profitability or reduce risk. While some of these studies were helpful, the economic potential of the technology may be understated to the extent that substitution of inputs and alteration of production practices were not addressed in these models. Widespread interest, coupled with the scarcity of studies, motivates the incorporation of this technology into a more complete whole farm planning model. By including alternative production practices, economic optimization can be achieved. In turn, this allows investigation into the full potential of auto-steer on the farm.

Few researchers conducted in-depth risk analyses of precision agriculture technologies, beyond the present focus of this study. Dillon et al. (2005) conducted educational workshops to inform farmers of the risk management potential of precision agriculture. Oriade and Popp (2000) conducted a whole farm planning model of precision agriculture technology where risk was incorporated. However, the lack of yield data, and the interactive effects of production practices, necessarily led to overly restrictive assumptions and results. Others have developed theoretical models that suggested variable rate technology could be utilized in managing production risk (Lowenberg-DeBoer, 1999). The investigation into auto-steer as a risk management tool was meager, therefore it became an objective of this study.

The objectives of this study are to: (1) determine profitability of auto-steer under various scenarios; (2) determine if auto-steer can be utilized as a tool for risk management; (3) determine optimal production practices under various scenarios with and without auto-steer; (4) determine the break-even acreage level, payback period, and return on investment for the adoption of auto-steer; and (5) determine the impact of input price on the profitability of auto-steer. A whole farm economic model is used to provide a detailed assessment of auto-steer options for a hypothetical grain farm in Kentucky. Due to the adoption trend for auto-steer by Kentucky farmers, investigations are undertaken considering three scenarios: (1) the addition of a bolt-on auto-steer system with a sub-meter receiver on a self-propelled sprayer, (2) the addition of an integral valve auto-steer system with an RTK GPS receiver on a tractor, and (3) the addition of both auto-steer systems to the farm enterprise. Scenario three investigates the situation in which a farmer is utilizing sub-meter auto-steer on the sprayer and an RTK auto-steer on the tractor. Hence, the benefits and costs of both systems are incorporated into the model. All five of the above objectives are investigated for each of the above scenarios as well as incorporating four farmer risk aversion attitudes: neutral, low, medium, and high risk aversion for objectives one through four. The four risk aversion levels represent a desire to maximize net returns that are 50%, 65%, 75%, and 90% likely to be achieved for neutral, low, medium, and high risk aversion levels, respectively.

Analytical Procedure

The experimental framework for this study includes the production environment, the economic

Table 1. Summary of Corn Production Practices Utilized within this Study[a]

Planting Date	March 25, April 1, April 8, April 15, April 22, April 29, May 6, May 13, May 20
Maturity group (growing degree days)	2,600–2,650, 2,650–2,700, 2,700–2,750
Plant population (plants/acre)	24,000; 28,000; 32,000
Row spacing	30″
Plant depth	1.5″
Nitrogen rate (actual lbs/acre)	100, 150, 175, 200, 225
Summary of Soybean Production Practices Utilized within this Study	
Planting date	April 22, April 29, May 6, May 13, May 20, May 27, June 3, June 10, June 17
Maturity group	MG2, MG3, MG4
Plant population (plants/acre)	111,000; 139,000; 167,000
Row spacing	15″, 30″
Plant depth	1.25″

[a] Both corn and soybean production practices chosen for this investigation were consistent with the University of Kentucky Cooperative Extension Service grain crop recommendations.

optimization whole farm model, and the specific conditions and resource base of the hypothetical farm that represents the study focus. These are each discussed in turn to establish the analytical framework of the study.

The Production Environment

Production data estimates were determined using Decision Support System for Agrotechnology Transfer (DSSAT v4), a biophysical simulation model (Jones et al., 2003). DSSAT has provided underlying production data for almost 15 years in studies covering a multitude of geographic locations and experimental requirements as evidenced by relevant refereed publications in numerous journals. When coupled with the validation specific to the study at hand, as discussed later, DSSAT was determined to be an appropriate model for this study.

The minimum input required to develop yield estimates in DSSAT includes site weather data for the duration of the growing season, site soil data, and definition of production practices. Site weather data were obtained from the University of Kentucky Agricultural Weather Center (2008). Daily climatology data were collected for 30 years in Henderson County, Kentucky. Soil data were obtained from a National Cooperative Soil Survey of Henderson County, Kentucky from the United States Department of Agricultural (USDA) Natural Resources Conservation Service (NRCS) (2008). After identifying all soil series located in Henderson County, information on those soil series was gathered using the NRCS Official Soil Series Description from their website. Four representative soils (deep silty loam, deep silty clay, shallow silty loam, and shallow silty clay) were utilized in the biophysical simulation models. Finally, numerous production practices were defined to complete the minimum requirements to operate DSSAT. Production practices were identified for both corn and full season soybeans in accordance with the University of Kentucky Cooperative Extension Service Bulletins (2008). Varying production practices utilized in this study included planting date, crop variety, plant density, row spacing, and fertilizer practices (Table 1).

A comprehensive validation was performed on the response of yield estimates to varying production practices and compared with pertinent literature. For instance, the response of corn yield to nitrogen rates exhibited a quadratic response which was consistent with previous studies (e.g., Schmidt et al., 2002; Cerrato and Blackmer, 1990). Also, comparisons of simulated to actual historical yield trends were made for Henderson County, Kentucky. Regression analyses were conducted, in which *t*-tests confirmed that the simulated yields for both corn and soybeans were not statistically different from the actual historical yields, with a significance of 99%.[1] Discussions with specialists were also conducted to confirm that the simulated yield results were reasonable. Overall, yield estimates were believed to be representative of production in Henderson County, Kentucky. These yield data were a key element of the economic model.

The Economic Model

The economic framework of a commercial Kentucky corn and soybean producer under no-till conditions was embodied in a resource allocation model employed within a mean-variance (E-V) quadratic programming formulation. The model incorporated risk, as measured by the variance of net returns across years, which was consistent with formulations developed by Freund (1956). Specifically, the model was modified from Dillon's (1999) risk management model to include additional production practices such as nitrogen rate and row spacing. The model was also modified by allowing multiple weeks for harvesting. In addition, four land types were incorporated within the model. Finally, the inclusion of various auto-steer scenarios distinguished this model from Dillon's (1999) model.

The objective of this model was to maximize net returns above selected costs less the Pratt risk aversion function coefficient multiplied by the variance of net returns (referred to hereafter as expected net returns). The mathematical representation of the model can be found in the Appendix. The selected costs incorporated in the model included input variable costs (fertilizer, herbicide, seed, hauling, and custom application of lime, phosphorous, and potassium), operating costs (labor, fuel, repairs and maintenance, and interest on operating capital), and the ownership cost of auto-steer. The Pratt risk aversion coefficient measured a hypothetical producer's aversion to risk and was in accordance with the method developed by McCarl and Bessler (1989). Intuitively, the model represented the typical risk-return tradeoff in which the model discounts the expected net returns by the variance of net returns.

The economic model included decision variables, constraints, and other data and coefficients. The decision variables for the model were the land area in corn and soybean production. These were identified by alternative production possibilities and soil types (Table 1).[2] Based on the decision variables, expected average yields and net returns were calculated. For the model to determine these decision variables, constraints were required within the model.

Constraints included land available, labor, crop rotation, and ratio of soil type. The land constraint guaranteed that the combined production of corn and soybeans did not exceed the available land assumed for this study. In addition, agricultural tasks performed in the production of both corn and soybeans were required. These tasks included: planting, spraying, fertilizing, and harvesting which were constrained by the estimated suitable field hours per week available for performing each operation. The rotation constraint required 50% of the land to produce corn and 50% to produce soybeans. This represented a 2-year crop rotation typical of a Kentucky grain producer. Furthermore, constraints were required to ensure that production practices were uniformly distributed across all soil types. This implied that variable rate by soil types could not occur.

Besides the constraints, additional information required within the model included establishing the coefficients, data, and further assumptions of the model. The coefficients necessary for this investigation included labor hours and the prices for corn and soybeans. Labor hours for producing corn or soybeans were based on the field capacities of the operating machines. To determine the total labor required for each operation, a 10% increase in field capacities was employed. This reflected additional labor required for performing other tasks such as travelling from field to field, refilling the seed bins and sprayer tanks, and

[1] The R^2 for corn and soybean regression analyses were 0.22 and 0.46, respectively.

[2] The economic model had the ability to choose various production alternatives across the allotted acres for all scenarios including the base case with no auto-steer technologies.

unloading the grain bin. Furthermore, the prices of corn and soybeans were also necessary for this analysis. Prices for corn and soybeans were determined from the World Agricultural Outlook Board (2008). Prices used were the 2009 median estimates less Kentucky's basis, which resulted in \$9.75/bu and \$4.25/bu for soybeans and corn, respectively.

Supplementary data crucial for this investigation included the proper land area, suitable field hours, and the cost of auto-steer. The land area chosen for this study was reflective of Henderson County, Kentucky. Henderson County ranks second in the state in both corn and soybean production (National Agricultural Statistics Service Kentucky Field Office, 2008). According to the Kentucky Farm Business Management Program, a 2,600 acre farm corresponded to the upper one third of all farms in management returns as represented by net farm income in the Ohio Valley region of Kentucky, where Henderson County is located (Pierce, 2008). Therefore, the acreage level assumed for this investigation was deemed an appropriate size. Suitable field days were calculated based on probabilities of it not raining 0.15 inches or more per day over a period of a month.[3] This was determined from the 30-year historical climatological dataset previously mentioned. The probabilities were multiplied by the days worked in a week and hours worked in a day to determine expected suitable field hours per week. Moreover, the annualized ownership cost of both auto-steer systems included depreciation and the opportunity cost of capital invested. Depreciation of the auto-steer technologies were calculated using the straight-line method with an assumed 10-year useful life and no salvage value. The opportunity cost of capital investment was calculated using an 8% interest rate. A total investment of \$7,000 for auto-steer with a sub-meter receiver and \$35,000 for auto-steer with an RTK receiver was assumed. As a result, the annualized costs of sub-meter and RTK auto-steer were \$980 and \$4,900, respectively.[4] For the addition of both auto-steer systems, the costs were added together for a total investment of \$42,000, with an annualized cost of \$5,880 (Griffin, Lambert, and Lowenberg-DeBoer, 2005, 2008; Stombaugh, 2009; Stombaugh, McLaren, and Koostra, 2005).

Finally, there were two assumptions within the model in need of clarification. First, the amount of area initially overlapped by the sprayer and the amount of inward drift by the implements attached to the tractor without using auto-steer was assumed. Secondly, there was an increase in the operators work day due to the adoption of auto-steer. Unfortunately, scientific research pertaining to these factors was lacking since each was operator dependent. Therefore, these factors were evaluated over a range to provide general economic insight into the profitability of auto-steer under two technological scenarios. The technical coefficients of the model were varied to reflect various overlap and inward drift scenarios. The overlap scenarios for the sprayer were varied from 5 ft to 10 ft and the inward drift of implements on the tractor from 0.5 ft to 3 ft. By doing so, both field capacity and cost (inputs, labor, and fuel) for the relative machinery operations were affected. The operator's work day was also evaluated for various increases in hours worked per day which reflected the operator's ability to work longer hours with less fatigue. It was determined that varying the hours worked per day had no impact on profitability unless the farmer worked below the original hours assumed for the base case of 13 hours per day. On the other hand, the results from varying the overlapped area and inward drift of the implements were provided in the results section. To address the specific objectives of this study, inquiries into the appropriate overlap of the sprayer, inward drift of

[3] An example for determining suitable field days is given for clarification. Over the 30 year timeframe, the median days in January that it rained 0.15 inches or more was five. Therefore, the probability of it NOT raining 0.15 inches per day in January was (1-(days rained/days in the month)). This probability was used to estimate the number of suitable field days for the model.

[4] The annualized cost of an auto-steer technology was calculated using the following equation for the straight-line depreciation method plus the opportunity cost of capital represented by the average value times the interest rate. [((Total Investment – Salvage Value)/(Useful Life)) + ((Total Investment + Salvage Value) × Interest Rate)/2].

implements, and workday scenario were required to represent a Kentucky farmer, and discussed in the following section.

The Hypothetical Model Farm

A base machinery complement was determined for a hypothetical grain farm in Henderson County which practices no-till farming. The machinery set included one 250-hp 4WD tractor with the following implements: a split row no-till planter (16 rows), a 42-ft anhydrous applicator, a grain cart with 500 bushel capacity, and a 20-ft stalk shredder for corn. A 300-hp harvester was also utilized with an 8 row header for corn and a 25-ft flex header for soybeans. A self propelled sprayer with an 80-ft boom that applied herbicides on corn for pre-plant burn down and post planting weed control (glyphosate and atrazine), herbicides on soybeans for pre-plant burn down and post planting weed control (glyphosate and 2, 4-D, B), and insecticide on soybeans (acephate) completed the equipment set. All equipment specifications (e.g., speed, width, and efficiency) were from the Mississippi State Budget Generator (MSBG), which complies with the American Society of Agricultural and Biological Engineering Standards (Laughlin and Spurlock, 2007). However, both the planter and applicator were added into MSBG with the appropriate data, which were compiled from the Illinois Farm Business Management (Schnitkey and Lattz, 2008) machinery operation specifications. For the base case, no machines were equipped with any GPS-enabled navigation technologies.

It was recognized for the base machinery set that, due to operator error and/or fatigue and lack of navigational technologies, varying overlaps occurred. The degree of overlap depended on the timing of application (i.e., pre-plant or post-plant). For this study, the focus was on the overlap of the self-propelled sprayer and the inward drift of the implements attached to the tractor since those machines would be most impacted by auto-steer. First, an overlap of 10% of the equipment width was assumed for the pre-planting operations of the self propelled sprayer, hence eight ft of overlap (Griffin, Lambert, and Lowenberg-DeBoer, 2008; Palmer, 1989). Next, it was assumed that the planter passes would drift inward by one foot on average per acre. Due to operator error and inward drift of the planter more rows per acre are planted than considered optimal. Since more rows are planted than optimal, a farmer could incur a larger seed cost. Therefore, all operations following planting would be drift inward by one foot on average per pass since the implements would follow the enterprise row (Stombaugh, 2009). By adopting auto-steer navigation the above overlaps and inward drifts could potentially be reduced.

When adopting bolt-on auto-steer with a sub-meter receiver on the self-propelled sprayer, a reduction in overlap from 8 ft to 3 ft for pre-planting operations was utilized (Stombaugh, McLaren, and Koostra, 2005). There was no reduction in overlaps for post-planting operations due to the base accuracy of the planter (one ft overlap) since post planting operations would follow the enterprise row. When adopting an integral valve auto-steer system with an RTK base station, reductions in inward drifts from 1 ft to 1 inch were utilized for implements operated by the tractor. By utilizing RTK, the total number of rows planted is reduced; therefore there is the possibility for seed cost savings (Stombaugh, McLaren, and Koostra, 2005).

The potential benefits of auto-steer not only included a reduction in overlap and inward drift but also an increase in field speed and length of operator's work day. For the sprayer, it was assumed field speeds increased 20% for pre-planting applications and 10% for post-planting applications. An increase in speeds were assumed because of the ability to drive faster during headland turns and the ability to quickly determine which row to enter to continue operating. Speed increases of 5% for planting and 10% for both fertilizer application and stalk shredding were also assumed (Stombaugh, 2009). With the above benefits of both auto-steer systems quantified, a percent multiplier was computed and implemented to calculate the new field capacities for the appropriate machines and the reduction in the impacted input costs (Table 2). Only the reduction in overlap and inward drift was considered for calculating the multiplier for reduced input costs.

In addition, suitable field days were altered to represent the adoption of auto-steer

Table 2. Base Field Capacities, as well as New Field Capacities when Auto-Steer is Adopted on the Self-Propelled Sprayer and Tractor

Implement	Old Field Capacity (hr/ac)	New Field Capacity (hr/ac)[a]	Multiplicative Factor[b]
Sprayer: Pre-Plant	0.0132	0.0103	0.7792
Sprayer: Post-Plant	0.0132	0.0120	0.9090
Herbicide Cost			0.9306
Planter	0.0491	0.0457	0.9305
Seed Cost			0.9765
Anhydrous Applicator	0.0491	0.0437	0.8892
Nitrogen Cost			0.9776
Stalk Shred	0.0825	0.0715	0.8672

[a] New field capacities are calculated according to the changes in width and speed due to the adoption of auto-steer. These field capacities directly impacted the total labor (hrs) used in each scenario.
[b] The multiplicative factor represents the percent change between the new and old field capacities. For example, sub-meter auto-steer decreased the hours per acre for pre-planting application of chemicals by approximately 22%. The multiplicative factor related to input cost represents the reduction in cost due solely to the reduction in overlap or inward drift that occurred when adopting auto-steer.

by increasing the operator's workday from 13 hours to 15 hours. This was attributed to the ability of the operator to work further into the night with less fatigue (Griffin, Lambert, and Lowenberg-DeBoer, 2008).[5] To determine the influence of auto-steer on net returns, risk, and production practices, both old and new field capacities, as well as suitable field days, were utilized in the economic model.

Results and Discussion

Three auto-steer scenarios were investigated and then compared with the base scenario without auto-steer navigation: (1) the addition of a bolt-on auto-steer system with a sub-meter receiver on a self-propelled sprayer, (2) the addition of an integral valve auto-steer system with an RTK GPS receiver on a tractor, and (3) the addition of both auto-steer systems to the operation.

Sub-Meter Auto-Steer Results

The economic, risk, and production impacts of sub-meter auto-steer were first investigated. The addition of sub-meter auto-steer increased expected net returns under all four risk scenarios compared with the base without navigational technology (Table 3). Across all risk aversion levels, the average increase in expected net returns was 0.58% ($2.14/acre).[6] Also, the minimum and maximum net returns were both higher compared with the base scenario for all risk aversion levels.

The break-even acreage level, payback period, and the return on investment for the adoption of sub-meter auto-steer were also determined. To spread out the fixed cost associated with sub-meter auto-steer, a land area of 394 acres was required under the risk neutral scenario.[7] According to the 2007 Census of Agriculture, approximately 13% of the grain farms in Kentucky exceed the break-even acreage level and would be candidates for sub-meter auto-steer for the conditions analyzed (U.S.

[5] Scientific research for determining increased work hours is non-existent since it is the farmer's preference on how many hours are worked each day, but it is known that farmers have the ability to work longer hours due to auto-steer if they wish. Therefore, alterations in suitable field days were modeled after the cited study.

[6] For the risk neutral scenario, if the operator overlapped by only 5 ft, net returns increased by 0.17% with a return on investment of 29.33%. On the other hand, if the operator overlapped by 10 ft, the net returns increased by 0.79% with a return on investment of 119.04%. Note: Base overlap for the self-propelled sprayer was 8 ft.

[7] Break-even acreage level could not be determined based solely on a calculation. Both the base scenario and the specific auto-steer scenarios acreage level were varied within the model such that both their expected net returns converged. Once the net returns for each model converged, the break-even acreage level was determined.

Table 3. Economics of Auto-Steer Navigation under Various Risk Aversion Scenarios

	Risk Aversion Levels			
Base[a]	Neutral	Low	Medium	High
Expected Net Returns	$1,020,336	$996,251	$961,761	$908,897
Percent Optimal	100.00%	100.00%	100.00%	100.00%
C.V. (%)	17.81	14.78	13.00	10.90
Minimum Net Returns	$658,928	$678,852	$684,355	$706,205
Maximum Net Returns	$1,364,489	$1,313,763	$1,235,161	$1,123,673
Sub-Meter[b]				
Expected Net Returns	$1,025,835	$1,001,797	$967,527	$914,387
Percent Optimal	100.54%	100.56%	100.60%	100.60%
C.V. (%)	17.72	14.70	12.94	10.84
Minimum Net Returns	$664,350	$684,310	$687,922	$711,695
Maximum Net Returns	$1,370,054	$1,319,393	$1,241,078	$1,129,163
RTK[c]				
Expected Net Returns	$1,023,618	$1,000,645	$964,242	$911,256
Percent Optimal	100.32%	100.44%	100.26%	100.26%
C.V. (%)	17.76	14.84	12.97	10.88
Minimum Net Returns	$662,133	$681,971	$688,020	$708,385
Maximum Net Returns	$1,367,838	$1,321,461	$1,237,622	$1,126,714
Both[d]				
Expected Net Returns	$1,029,108	$1,006,135	$970,101	$916,747
Percent Optimal	100.86%	100.99%	100.87%	100.86%
C.V. (%)	17.66	14.76	12.90	10.81
Minimum Net Returns	$667,623	$687,460	$691,501	$713,874
Maximum Net Returns	$1,373,328	$1,326,952	$1,243,633	$1,132,204

[a] Base refers to operating without any auto-guidance systems.
[b] Sub-Meter refers to the adoption of a bolt-on auto-steer system with a sub-meter receiver on a self propelled sprayer.
[c] RTK refers to the adoption of an integral valve auto-steer system with an RTK GPS receiver on a tractor.
[d] Both refers to the adoption of both auto-steer systems above and operating together.

Department of Agriculture-National Agricultural Statistics Service, 2010). Also, the payback period was calculated under the risk neutral scenario, and sub-meter auto-steer was able to pay for itself in 1.08 years for farms with 2,600 acres. Furthermore, sub-meter auto-steer had an 82.56% return on investment.[8]

In addition to determining the economic impact of sub-meter auto-steer, investigating its potential to become a tool for risk management was also an objective. For this study, production risk was measured by the coefficient of variation (C.V.) of net returns across years. If the adoption of sub-meter auto-steer decreased the C.V. as well as increased expected net returns when compared with the base scenario, it could be inferred that the technology could be used to manage production risk. Evidence of reduced risk through sub-meter auto-steer was displayed by more favorable C.V. across risk aversion levels when compared with the base scenario. In addition, an increase in expected net returns occurred under all risk scenarios when compared

[8] The following formula was utilized to calculate the returns on investment: [(Net returns gained from technology) + (Opportunity cost of capital)]/(Total investment in the technology). The opportunity cost of capital was calculated using the following formula: (Interest rate × Total investment/2). The return on invest was adjusted such that the opportunity cost of capital was not accounted for twice. Therefore, the percentages appropriately reflected the return on the capital invested.

Table 4. Production Results and Acres Planted for Various Risk Aversion Levels under the Base Scenario with No Auto-Steer Navigational Technologies

Section 1. Corn Management Practices				Risk Aversion Levels			
Planting Date	Maturity Group	Plant Pop	Nitrogen Rate	Neutral	Low	Medium	High
March 25	2,600	28,000	150	0	111	359	460
March 25	2,650	24,000	150	0	251	0	0
March 25	2,650	32,000	150	362	0	0	0
March 25	2,700	24,000	100	0	0	0	129
March 25	2,700	24,000	150	0	0	373	0
March 25	2,700	28,000	175	0	501	0	0
March 25	2,700	32,000	175	722	0	0	0
April 1	2,700	24,000	100	0	0	0	231
April 1	2,700	28,000	100	0	0	132	0
April 1	2,700	28,000	150	0	0	83	0
April 1	2,700	32,000	150	0	185	0	0
April 8	2,600	24,000	100	0	0	0	264
April 8	2,700	28,000	150	0	36	119	0
April 15	2,700	28,000	225	216	0	0	0
April 22	2,650	28,000	150	0	216	234	216
			Yields[a]	163	156	152	146
Section 2. Soybean Management Practices[b]				Risk Aversion Levels			
Planting Date	Maturity Group			Neutral	Low	Medium	High
April 22	MG3			0	372	553	0
April 22	MG4			1,290	0	0	0
April 29	MG2			0	0	253	913
April 29	MG4			10	672	0	0
May 6	MG4			0	256	0	0
May 13	MG4			0	0	322	0
June 10	MG4			0	0	172	0
June 17	MG4			0	0	0	387
			Yields	62	62	60	57

[a] Yields for both corn and soybeans are in bu/acre.
[b] Optimal plant population and row spacing was the same for all risk scenarios of 111,000 plants per acre and 15 inch row spacing.

with the base scenario (e.g., 17.72[9] and $1,025,835 under risk neutrality compared with 17.81 and $1,020,336). The average decrease in C.V. due to the adoption of sub-meter auto-steer was 0.07%. As a result, it was determined that sub-meter auto-steer could be used as a tool for risk management. The farm manager's capability to alter production practices was a large contributor in reducing the C.V.

It was also determined that the optimal production practices for the base scenario (Table 4) were altered when sub-meter auto-steer was adopted (Table 5). This demonstrated the importance of a whole farm analysis and the need to adjust production practices to take full advantage of the new technology. The majority of changes occurred in the production of

[9] ±17.72% of mean net returns occur in about 2/3 of the years. C.V. is a relative measure of risk with a decrease representing a reduction in risk.

Table 5. Production Results and Land Area Planted for Various Risk Aversion Levels under Sub-Meter Auto-Steer

Section 1. Corn Management Practices

Planting Date	Maturity Group	Plant Pop	Nitrogen Rate	Risk Aversion Levels			
				Neutral	Low	Medium	High
March 25	2,600	28,000	150	0	111	345	460
March 25	2,650	24,000	150	0	251	0	0
March 25	2,650	32,000	150	362	0	0	0
March 25	2,700	24,000	100	0	0	0	129
March 25	2,700	24,000	150	0	0	383	0
March 25	2,700	28,000	175	0	501	0	0
March 25	2,700	32,000	175	722	0	0	0
April 1	2,700	24,000	100	0	0	0	231
April 1	2,700	28,000	100	0	0	127	0
April 1	2,700	28,000	150	0	0	91	0
April 1	2,700	32,000	150	0	185	0	0
April 8	2,600	24,000	100	0	0	0	264
April 8	2,700	28,000	150	0	36	121	0
April 15	2,700	28,000	225	216	0	0	0
April 22	2,650	28,000	150	0	216	233	216
			Yields[a]	163	156	152	146

Section 2. Soybean Management Practices[b]

Planting Date	Maturity Group	Risk Aversion Levels			
		Neutral	Low	Medium	High
April 22	MG3	0	370	506	0
April 22	MG4	1,300	0	0	0
April 29	MG2	0	0	255	913
April 29	MG3	0	0	0	0
April 29	MG4	0	685	0	0
May 6	MG4	0	245	0	0
May 13	MG4	0	0	405	0
June 17	MG4	0	0	133	387
	Yields	62	62	60	57

[a] Yields for both corn and soybeans are in bu/acre.

[b] Optimal plant population and row spacing was the same for all risk scenarios of 111,000 plants per acre and 15 inch row spacing.

soybeans. For example, there was a removal of planting on April 29 with maturity group four under risk neutrality. This was due to the competition for suitable field hours during the week of planting of soybeans on April 22 with spraying post-emergence herbicide on corn planted on March 25. With the ability to spray more effectively with sub-meter auto-steer, more suitable field hours were available for planting the highest yielding soybean planting date/maturity group combination.

The largest change that occurred due to the adoption of sub-meter auto-steer was for medium risk aversion. Planting the week of June 10 with maturity group four was removed from the optimal production set and replaced with planting the week of June 17 with maturity group four. This was due to the competition of suitable field hours during the week of spraying insecticide on soybeans planted on the week of May 13 with harvesting the corn planted on March 25 with maturity group 2,600. Soybeans planted on May 13 exhibited the highest yield potential of all planting dates in the optimal set. Therefore, as sub-meter auto-steer improved the efficiency of the sprayer, more acres were planted on the highest yielding planting date (May 13). However, planting more soybeans on May 13 increased the standard deviation of yields, hence net returns, which were penalized in the E-V framework. Therefore, substitution occurred from planting on June 10, which had the second largest standard deviation (behind May 13), with planting on June 17, which had a lower standard deviation with minimal reduction in yield (<1 bu per acre). As a result, planting soybeans on June 17 became part of the optimal set, while planting soybeans on June 10 was removed. Even though there were modifications to the optimal production set when compared with the base scenario with no auto-steer navigation, the average yields of soybeans were not altered.

Unlike soybeans, corn production practices in the optimal set were not changed compared with the base scenario without sub-meter auto-steer. There was a redistribution of acres within the optimal set for all risk aversions, but no more than 15 acres were reallocated. Since there was no considerable change in the production of corn, average yields remained the same.

RTK Auto-Steer Results

The economic, risk, and production implications of adopting an integral valve auto-steer system with an RTK GPS receiver on a tractor were also examined. Consequently, the farm operations of planting, fertilizing, and stalk shredding, which require a tractor, were relevant for consideration. With the adoption of RTK, expected net returns increased under all four risk scenarios when compared with the base (Table 3). Across all risk aversion levels, the average increase in expected net returns was 0.32% ($1.20/acre).[10] When compared with the addition of a bolt-on auto-steer system with a sub-meter receiver on a self-propelled sprayer, expected net returns across all risk levels was lower. However, the minimum and maximum net returns were higher compared with the base scenario for all risk aversion levels.

The break-even acreage level, payback period, and the return on investment for the adoption of RTK auto-steer were also determined. The break-even acreage under the risk neutral scenario was 1,553 acres. According to the 2007 Census of Agriculture, approximately 1% of the grain farms in Kentucky exceed the break-even acreage level and would be candidates for RTK auto-steer for the conditions analyzed. Also, the payback period was calculated under the risk neutral scenario and it was determined that RTK auto-steer would pay for itself in 4.28 years for farms with 2,600 acres. In addition, RTK auto-steer had an 11.15% return on investment. While these results still seem favorable, the less expensive sub-meter auto-steer option was economically superior.

The possibility of RTK auto-steer to reduce production risk was also examined. Similar to the sub-meter auto-steer scenarios, RTK exhibited the ability to reduce risk by exemplifying a more favorable coefficient of variation across risk aversion levels when compared with the base scenario except for the low risk aversion level. In addition, an increase in expected net returns occurred under all risk scenarios (e.g., 17.76 and $1,023,618 under risk neutrality compared with 17.81 and $1,020,336). The average C.V. across 30 years increased under the low risk aversion scenario. However, after investigating the risk-adjusted net returns (Z-Value), results indicated that RTK auto-steer had superior risk reducing properties compared with the base and sub-meter auto-steer. The higher C.V. indicated that the producer was willing to experience greater variability to achieve the higher expected net returns. For the scenarios where C.V. decreased, the average was 0.03%. As a result, it was determined that RTK auto-steer could be used as a tool for risk management for farmers. The farm manager's capability to alter production practices was a large contributor in reducing the C.V., hence offering the possibility to manage production risk.

[10] For the risk neutral scenario, if the implements drifted inward by only 0.5 ft, net returns decreased by −0.04% with a return on investment of 2.91% which is less than the interest rate of 8% assumed for this study. On the other hand, if the implements drifted inward by 3 ft, the net returns increased by 2.47% with a return on investment of 76.00%. Note: Base inward drift for the implements was 1 ft per pass.

Table 6. Production Results and Land Area Planted for Various Risk Aversion Levels under RTK Auto-Steer

Section 1. Corn Management Practices

Planting Date	Maturity Group	Plant Pop	Nitrogen Rate		Risk Aversion Levels Neutral	Low	Medium	High
March 25	2,600	28,000	150		0	167	374	465
March 25	2,650	24,000	150		0	150	0	0
March 25	2,650	28,000	150		0	45	0	0
March 25	2,650	32,000	150		362	0	0	0
March 25	2,700	24,000	100		0	0	0	128
March 25	2,700	24,000	150		0	0	356	0
March 25	2,700	28,000	175		0	520	0	0
March 25	2,700	32,000	175		722	0	0	0
April 1	2,700	24,000	100		0	0	0	232
April 1	2,700	28,000	100		0	0	121	0
April 1	2,700	28,000	150		0	0	95	0
April 1	2,700	32,000	150		0	177	0	0
April 8	2,600	24,000	100		0	0	0	258
April 8	2,700	28,000	150		0	25	121	0
April 15	2,700	28,000	225		216	0	0	0
April 22	2,650	28,000	150		0	216	234	216
				Yields[a]	163	156	152	146

Section 2. Soybean Management Practices[b]

Planting Date	Maturity Group		Risk Aversion Levels Neutral	Low	Medium	High
April 22	MG3		0	334	555	0
April 22	MG4		1,300	0	0	0
April 29	MG2		0	0	251	912
April 29	MG4		0	966	0	0
May 6	MG4		0	0	0	0
May 13	MG4		0	0	320	0
June 10	MG4		0	0	174	0
June 17	MG4		0	0	0	388
		Yields	62	62	60	57

[a] Yields for both corn and soybeans are in bu/acre.
[b] Optimal plant population and row spacing was the same for all risk scenarios of 111,000 plants per acre and 15 inch row spacing.

Production practices under the base scenario (Table 4) were also altered due to the adoption of RTK auto-steer (Table 6). Unlike sub-meter auto-steer, RTK impacted optimal corn production practices as well as soybean production practices. The largest change occurred under low risk aversion where corn planted on March 25 with a maturity of 2,650 growing degree days, 28,000 plants/acre, and nitrogen application rate of 150 lbs/acre was added to the optimal production set of corn. Additionally, planting soybeans on May 6 with maturity group four was removed from the optimal production set of soybeans. Both of these results were attributed to the competition for suitable field hours under various production practices. Specifically, there was competition during the week of planting soybeans on April 29, fertilizing corn planted on

March 25, and spraying herbicide on corn planted April 1. RTK auto-steer increased the efficiency of tractor operations (both planting and fertilizing), which allowed more acres of soybeans that could be planted on April 29. Therefore, May 6 was removed from the optimal set. Moreover, improvement in fertilizer efficiency allowed for more acres to be planted on March 25, therefore March 25 with a maturity of 2,650 growing degree days, 28,000 plants/acre, and nitrogen application rate of 150 lbs/acre was added to the optimal production set of corn.

Two interesting results occurred under risk neutrality and medium risk aversion. Similar to sub-meter auto-steer, planting soybeans during the week of April 29 was also removed from the optimal set under risk neutrality. This was attributed to the competition for suitable field hours during the week of planting soybeans and spraying corn. The difference was that RTK increased the efficiency of planting whereas sub-meter auto-steer increased the efficiency of spraying. However, the change in the production of soybeans remained the same. For medium risk aversion, planting the week of June 10 with maturity group four was not removed from the optimal set like the occurrence with the adoption of sub-meter auto-steer. This was because the competition for suitable field days was between spraying soybeans and harvesting corn, neither of which were influenced by RTK in this study. In addition, soybean yields were not impacted by the utilization of RTK.

Sub-Meter and RTK Auto-Steer Results

Similar to the first two investigations, the economic, risk, and production impacts were analyzed for both auto-steer systems operating together. The adoption of both auto-steer systems increased the expected net returns under all four risk scenarios when compared with the base scenario (Table 3). Across all risk aversion levels, the average increase in expected net returns was 0.90% ($3.35/acre). When compared with the addition of a bolt-on auto-steer system with a sub-meter receiver on a self-propelled sprayer, the average increase in expected net returns across all risk levels was 0.32% ($1.20/acre). When compared with the addition of an integral valve auto-steer system with an RTK GPS receiver on a tractor, the average increase in expected net returns across all risk levels was 0.58% ($2.15/acre). Also, the minimum and maximum net returns were higher compared with the base scenario for all risk aversion levels.

The break-even acreage level, payback period, and the return on investment for the adoption of both auto-steer systems were also determined. The break-even acreage under the risk neutral scenario was 1,056 acres. According to the 2007 Census of Agriculture, approximately 3% of the grain farms in Kentucky exceed the break-even acreage level and would be candidates for both auto-steer systems for the conditions analyzed. Also, the payback period was calculated under the risk neutral scenario and it was determined that the addition of both auto-steer systems would pay for themselves in 2.91 years for farms with 2,600 acres. Furthermore, the addition of both auto-steer systems had a 24.38% return on investment. These results were superior to operating with only RTK auto-steer but not superior to operating with sub-meter auto-steer alone.

The possibility of utilizing both auto-steer systems for reducing production risk was also an objective. The addition of both auto-steer systems exhibited the greatest ability to reduce risk. When compared with other auto-steer scenarios, both coefficient of variations and expected net returns were favored. The average decrease in the C.V. was 0.09%; therefore the addition of both auto-steer systems could be used as a risk management tool. Similar to the first two investigations, the farm manager's capability to alter production practices was a large contributor in reducing the C.V., hence the possibility to managing production risk.

Alterations in the base production practices of corn and soybeans (Table 4) due to the adoption of both auto-steer systems were also investigated. When adding both auto-steer systems, production practices and division of acres were similar as the scenario when adding just RTK auto-steer (Table 7). Only a few differences occurred within the optimal production set. The alterations in production practices when using both systems independently were seen when joined together in this analysis. Notably, there was the removal of planting soybeans on April 29 under risk

Table 7. Production Results and Land Area Planted for Various Risk Aversion Levels under Both Auto-Steer Scenarios

Section 1. Corn Management Practices

Planting Date	Maturity Group	Plant Pop	Nitrogen Rate		Risk Aversion Levels Neutral	Low	Medium	High
March 25	2,600	28,000	150		0	167	354	465
March 25	2,650	24,000	150		0	150	0	0
March 25	2,650	28,000	150		0	45	0	0
March 25	2,650	32,000	150		362	0	0	0
March 25	2,700	24,000	100		0	0	0	128
March 25	2,700	24,000	150		0	0	370	0
March 25	2,700	28,000	175		0	520	0	0
March 25	2,700	32,000	175		722	0	0	0
April 1	2,700	24,000	100		0	0	0	232
April 1	2,700	28,000	100		0	0	116	0
April 1	2,700	28,000	150		0	0	104	0
April 1	2,700	32,000	150		0	177	0	0
April 8	2,600	24,000	100		0	0	0	258
April 8	2,700	28,000	150		0	25	123	0
April 15	2,700	28,000	225		216	0	0	0
April 22	2,650	28,000	150		0	216	233	216
				Yields[a]	163	156	152	146

Section 2. Soybean Management Practices[b]

Planting Date	Maturity Group		Risk Aversion Levels Neutral	Low	Medium	High
April 22	MG3		0	334	507	0
April 22	MG4		1,300	0	0	0
April 29	MG2		0	0	255	912
April 29	MG4		0	966	0	0
May 6	MG4		0	0	0	0
May 13	MG4		0	0	404	0
June 10	MG4		0	0	6	0
June 17	MG4		0	0	129	388
		Yields	62	62	60	57

[a] Yields for both corn and soybeans are in bu/acre.

[b] Optimal plant population and row spacing was the same for all risk scenarios of 111,000 plants per acre and 15 inch row spacing.

neutrality (occurred under sub-meter and RTK investigations) and soybeans planted May 6 under low risk aversion (occurred under RTK investigation). Furthermore, planting corn on March 25 with a maturity of 2,650 growing degree days, 28,000 plants/acre, and nitrogen application rate of 150 lbs/acre was added to the optimal production set (occurred under RTK investigation). More importantly was the competing production decision under medium risk aversion between planting soybeans on June 10 as selected under the RTK optimal solution or June 17 as selected under the sub-meter optimal solution. Therefore, when the auto-steer systems were combined, the interactive production effects were seen. When operating with both auto-steer systems, both planting dates were part of the optimal production set. However, the noticeable dominance of sub-meter auto-steer was evident by the minuscule amount of soybeans planted on June 10.

Table 8. Expected Net Returns as well as Profitability of Auto-Steer above the Base Case (%) as Input Prices Fluctuate by the Percentages Indicated[a]

	Sub-Meter[b]	RTK[c]		Both[d]		
	Herbicide	Nitrogen	Seed	Herbicide	Nitrogen	Seed
20%	0.65	0.36	0.42	0.98	0.91	0.98
10%	0.60	0.34	0.37	0.92	0.88	0.92
0%	0.54	0.32	0.32	0.86	0.86	0.86
−10%	0.48	0.32	0.27	0.80	0.85	0.80
−20%	0.43	0.30	0.23	0.74	0.83	0.75

[a] The percentages indicate the increase in net returns above the base scenario with the same increase in input price.
[b] The impact of herbicide price fluctuations on the profitability of sub-meter auto-steer on the self-propelled sprayer when compared with the base case.
[c] The impact of nitrogen and seed price fluctuations on the profitability of RTK auto-steer on the tractor when compared with the base case.
[d] The impact of herbicide, nitrogen, and seed price fluctuations on the profitability of both sub-meter auto-steer on the self-propelled and RTK auto-steer on the tractor when compared with the base case.

Impact of Input Price on the Profitability of Auto-Steer

Sensitivity analyses were conducted to determine the impact of input price fluctuations on the net returns and profitability of auto-steer under the risk neutral scenario. Three inputs were investigated, herbicide, nitrogen, and seed prices. However, only the inputs that each auto-steer scenario impacted were analyzed. Specifically, sub-meter auto-steer influences herbicide costs because it was on the sprayer. Additionally, RTK auto-steer influences nitrogen and seed cost because it was on the tractor. When the technologies were combined, they influenced all three inputs. Each input price was varied from −20% to 20% of the base, *ceteris paribus*. Net returns for the base case and all three auto-steer scenarios were observed when input prices were varied (Table 8). As input prices were varied, the percent increase in profitability above the base case due to the adoption of auto-steer was also calculated. For example, when herbicide price increased by 20%, there was an increase of 0.65% in profitability over the base scenario due to the adoption of sub-meter auto-steer. As the appropriate input price increased, auto-steer became more profitable. Also, as input price decreased, auto-steer became less profitable. When operating with both auto-steer systems, seed price increases provided greater potential for profitability than nitrogen price increases. Conversely, nitrogen price decreases provided greater potential for profitability than herbicide price decreases.

Conclusion

A whole farm economic model is used to assess three auto-steer scenarios for various risk aversion levels. First, a general investigation into the increase in net returns and return on investment for auto-steer under various overlap and inward drift scenarios and hours worked per week are conducted. Results indicate that at the lowest overlap scenario, sub-meter auto-steer is profitable and the return on investment is always substantially larger than the interest rate. However, at the lowest inward drift scenario for RTK, auto-steer was not profitable and the return on investment was lower than the interest rate. Therefore, if the inward drift of the implements was only 0.5 ft., RTK would not be an economically viable option for a farm size of 2,600 acres. A base overlap, inward drift, and hours worked per day are assumed and a more thorough investigation is conducted.

The objectives of this study are to determine the economic, risk, and production implications due to the adoption of auto-steer. It is sufficient that the input savings that occur due to the reduction in total overlapped area be greater than the annual cost of auto-steer for it to be considered profitable. For all risk levels, results indicate that all three auto-steer scenarios are profitable when compared with the base, with the greatest average increase in expected net returns of 0.90% ($3.35/acre) for the scenario with both auto-steer systems. In addition, the minimum and maximum net returns that occur over 30 years are both higher due to the adoption of auto-steer. Furthermore, the break-even acreages under all scenarios are less than 1,555 acres, with a payback period of no more than 4.5 years. Also, the largest return on investment is 82.5% for sub-meter auto-steer.

The results also demonstrate that regardless of the auto-steer scenario or risk aversion level, the coefficient of variation decreases in all but one scenario. Nonetheless, when coupled with an increase in net returns, auto-steer can be used to manage production risk. However, reduced production risk is based mainly on the farm manager's capability to alter production practices.

The results of this investigation also indicate that the adoption of auto-steer can impact optimal corn and soybean production practices. Soybean production is impacted the most by the addition of sub-meter auto-steer navigation. When analyzing both auto-steer systems together, it is evident that sub-meter dominates RTK auto-steer when determining the optimal production practices. However, RTK does influence many facets of the optimal production set. This is due to the reduced overlap, reduced inward drift, and speed increases which results in an increase in the field capacity of sprayer and/or tractor. This in turn influences the competition between resources, specifically suitable field hours. Changes in the input price directly affect the expected net returns and the profitability of auto-steer. Although the increase in net returns are not substantial in magnitude, there are other benefits of auto-steer that cannot be quantified easily (e.g., the ability for the operator to multi-task and less fatigue). There exists opportunities for future research in quantifying these benefits, exploring how the quality of life of farmers is impacted by auto-steer, and how this influences its adoption.

When coupled with the ability to reduce production risk, these benefits provide sufficient evidence that auto-steer is a sound investment for this case study. The results demonstrate the potential of auto-steer to enhance net returns, reduce risk, and enable adjustments in optimal production practices. This has implications for farmers considering its adoption and use, extension personnel facilitating its adoption and use, researchers analyzing its potential, and the industry personnel in marketing of auto-steer.

[Received January 2010; Accepted September 2010.]

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APPENDIX: MATHEMATICAL SPECIFICATION OF THE ECONOMIC DECISION-MAKING MODEL

The economic decision-making model described in the text is depicted mathematically as follows:

Constraints include:

(1) Objective function
(2) Land resource limitation
(3) Labor resource limitation by week
(4) Sales balance by crop and year
(5) Input purchases by input

(1) $$\max \overline{Y} - \Phi\left[\sum_{YR}\left(\frac{1}{K-1}\right)(Y_{YR} - \overline{Y})^2\right]$$

subject to:

(2) $$\sum_{C}\sum_{V}\sum_{P}\sum_{S}\sum_{N}\sum_{R}\sum_{L}\sum_{H} X_{C,V,P,S,N,R,L,H} \leq 2600 \text{ acres}$$

(3)[12] $$\sum_{C}\sum_{V}\sum_{P}\sum_{S}\sum_{N}\sum_{R}\sum_{L}\sum_{H} LAB^{A}_{WK,V,S,C,H} X_{C,V,P,S,N,R,L,H} \leq FLDDAY^{A}_{WK} \; \forall \, WK$$

(4) $$\sum_{C}\sum_{V}\sum_{P}\sum_{S}\sum_{N}\sum_{R}\sum_{L}\sum_{H} EXPYLD_{C,V,P,S,N,R,L,YR} X_{C,V,P,S,N,R,L,H} - SALES_{C,YR} = 0 \; \forall \, YR$$

(5) $$\sum_{C}\sum_{V}\sum_{P}\sum_{S}\sum_{N}\sum_{R}\sum_{L}\sum_{H} REQ^{A}_{I,C,P,R} X_{C,V,P,S,N,R,L,H} - PURCH_{I} = 0 \; \forall \, I$$

(6) $$\sum_{I} IP_{I} PURCH_{I} - \sum_{C} P_{C} SALES_{C,YR} + Y_{YR} + TECHCOST = 0 \; \forall \, YR$$

(7) $$\sum_{YR} \frac{1}{K} Y_{YR} - \bar{Y} = 0$$

(8) $$\sum_{C}\sum_{V}\sum_{P}\sum_{S}\sum_{N}\sum_{R}\sum_{L}\sum_{H} ROTATE_{C} X_{C,V,P,S,N,R,L,H} \leq 1300 \text{ acres}$$

(9) $$SOILRATIO_{L_i} X_{C,V,P,S,N,R,L,H_j} - SOILRATIO_{L_j} X_{C,V,P,S,N,R,L,H_i} = 0 \; \forall \, L,C$$

Activities include:

$\overline{Y}$ = expected net returns above selected costs (mean across years);

Y_{YR} = net returns above selected costs by year (net returns);

$X_{C,V,P,S,N,R,L,H}$ = production of crop C of variety V with plant population P under sowing date S with nitrogen rate N and row spacing R on, land type L harvested in period H in acres;

$SALES_{C,YR}$ = bushels of crop C, sold by year;

$PURCH_{I}$ = purchases of input I;

(6) Net return balance by year
(7) Expected net return balance
(8) Rotation limitations
(9) Ratio of soil type

Coefficients include:

Φ = Pratt risk-aversion coefficient;

P_C = Price of crop C in dollars per bushel;

$EXPYLD_{C,V,P,S,N,R,L,YR}$ = Expected yield of crop C of variety V planted in population P planted on sowing date S with nitrogen rate N and row spacing R on land type L for year YR in bushels;

$REQ^{A}_{I,C,P,R}$ = Requirement of input I for production of crop C with plant population P and row spacing R for each auto-steer scenario in units per hectare. There was a separate input requirement for each auto-steer scenario A,

$LAB^{A}_{WK,V,S,C,H}$ = Labor requirements for production of crop C planted with variety V on sowing date S

[12] Three different auto-steer scenarios were investigated separately in which the coefficient *LAB* was adjusted to appropriately reflect each technology scenario. In addition, the coefficient *FLDDAY* and *REQ* in Equation 5 was also adjusted to appropriately reflect each auto-steer scenario.

in week WK harvested in period H in hours per acre. There was a separate labor requirement for each auto-steer scenario A;

$FLDDAY^{A}_{WK}$ = Available field days per week at varying probabilities. There were separate available field days per week for each auto-steer scenario A;

$TECHCOST$ = Cost of auto-steer for each scenario

$ROTATE_C$ = Rotation categorization matrix by crop C

$SOILRATIO_L$ = Ratio of total acres allotted for each soil type

K = Total number of years.

Indices include:

C = Crop
V = Maturity group
P = Plant population
S = Planting date
N = Nitrogen rate
R = Row spacing
L = Land type
YR = Year
H = Harvest period
I = Input
A = Auto-steer scenario
WK = Week