Economics of the Variable Rate Technology Investment Decision for Agricultural Sprayers

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Abstract: Producers lack information about the profitability of variable rate technology (VRT) for agricultural sprayers. An economic framework was developed to evaluate the returns required to pay for VRT investments. Payback variables include input savings, yield gains, and reduced application costs. We illustrate the framework with two example investment scenarios.

Keywords: capital budgeting, decision aid, farm management, precision agriculture, map-based, sensor-based, site-specific management, variable rate technology.

JEL Classifications: Q10, Q16

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Introduction

Variable rate technology (VRT) for agricultural sprayers has the potential to improve farm profits by lowering input and application costs and increasing yields. VRT helps producers identify input needs within a farm field, prescribe site-specific input application rates, and then apply those inputs as needed (Ess, Morgan, and Parsons, 2001). This contrasts with uniform rate technology (URT) where the goal is to maintain a constant application rate across the entire field. The profitability of VRT will vary from field to field depending on the degree of spatial variability and the quantity of chemical inputs applied (Roberts, English, and Larson, 2006). Such zones may be delineated by one or more characteristic, such as soil type, drainage, weed pressure, or crop biomass indices. Cost savings from VRT relative to URT will be greater in fields with greater spatial variability since the optimal application rate will also vary more.

The use of VRT for managing chemical input application may have great potential in cotton production. Cotton producers face many pre- and post-emergence input decisions involving herbicides, insecticides, plant growth regulators and harvest aids. Most are applied on a repetitive basis, resulting in increased chemical and application costs as compared to other crops. For example, the USDA reported an average chemical input cost of $68/acre for cotton production but only $28/acre for corn and $14/acre for soybeans for the period 2006-2007 (USDA-ERS, 2007). Results from a 2005 cotton precision farming survey conducted in 11 southern states indicated that 48% of respondents have already adopted some form of precision agriculture technology (Roberts et al., 2006). For continued adoption to occur, producers will need to receive more information about the returns needed to pay for the ownership and information costs associated with investing in precision equipment.

Early economic analyses of VRT systems for sprayer applied inputs focused on single-input herbicide application systems (e.g. Ahrens, 1994; Bennett and Pannell, 1998; Oriade et al., 1998). More recently, the economic benefits of VRT systems for multiple inputs have been considered (e.g. Larson et al. 2004, Gerhards and Christensen, 2003; Rider et al., 2006). Economic analyses of automatic boom control (Batte and Ehsani, 2006) and precision guidance (Buick and White, 1999; Ehsani, Sullivan, and Zimmerman, 2002; Griffin, Lambert, and Lowenberg DeBoer, 2005) have also shown potential for positive economic returns. Many of these studies, however, overlooked key equipment ownership and information-gathering costs such as spatial data acquisition, development of treatment maps, computer and data analysis training, and additional labor requirements (Griffin et al., 2004; Lambert and Lowenberg-DeBoer, 2001; Swinton and Lowenberg-DeBoer, 1998).

The objective of this article was to develop an economic framework that is useful for evaluating investments in VRT systems for agricultural sprayers. This objective was achieved through: (i) the identification of capital ownership and information-gathering costs associated with VRT adoption, (ii) the development of a partial budgeting framework to determine the returns required to pay for VRT investments, and (iii) illustration of the framework using three examples analyses for cotton production in West Tennessee.

VRT Equipment and Information Costs

Two methods of gathering site-specific crop information for applying inputs at variable rates are map-based VRT and sensor-based VRT (Ess, Morgan, and Parsons, 2001). In the map-based approach, a variable rate controller-monitor adjusts the target application rate based on the applicators exact field location and a computerized prescription application map. Maps are generally made using geographic information system software (GIS) and geo-referenced data on yield, soil properties, or crop biomass indices. A global positioning system (GPS) mounted onto the applicator is used to identify exact field location. Spatial data on crop and soil characteristics is often purchased from aerial or satellite imagery service providers.

In contrast, sensor-based approaches utilize vehicle-mounted sensors to obtain spatial data on crop and characteristics, and thus eliminate the need for subscription to a data service provider. Crop data may also be analyzed in real time so that inputs can be applied on-the-go without the need for GPS or GIS system components. Nonetheless, growers will likely continue using sensor-based technologies in combination with GPS and GIS technologies to keep input application records, compare annual variations in input use, or negotiate custom rates or land leases. The GPS and GIS components are also frequently used in other precision agriculture tasks (e.g., planting, fertilizer application, yield monitoring), making the use of such components likely even when on-the-go application is possible.

Equipment ownership costs for VRT systems include the initial investment required to purchase VRT equipment components and any increase in taxes, insurance, and storage. VRT information-gathering costs include all costs incurred on an annual basis and that are in excess of those costs normally incurred in URT. Such costs typically include acquisition of geo-referenced spatial data on crop characteristics, subscription to a GPS signal network, custom prescription map making, data analysis and training, and additional scouting or on-farm labor requirements. Aerial or satellite imagery for map-based VRT is generally charged on an annual, per-acre basis. In contrast, vehicle-mounted sensors for sensor-based VRT are typically owned by the producer and are treated as capital goods. It is important to note that some annual costs may decrease upon VRT adoption (e.g. foam markers) and partially offset any increase in information costs.

Partial Budgeting Framework

The partial budgeting equation used to analyze the returns required to pay for investments in VRT systems for agricultural sprayer was:

$$\Delta \mathrm{NR} = \sum_{\mathrm{i}=1}^{\mathrm{n}} [(\mathrm{P}\Delta \mathrm{Y}_{\mathrm{i}} - \mathrm{R}_{\mathrm{i}}\Delta \mathrm{X}_{\mathrm{i}})] - \Delta \mathrm{AOC} - \Delta \mathrm{SOC} - \Delta \mathrm{INFO}, \tag{1}$$

where ΔNR is the change in net return to sprayer operations following VRT adoption (\$/acre), P is lint price (\$/acre), ΔY_i is change in lint yield due to VRT input decision i (lbs/acre), ΔX_i is the change in the quantity of crop input i applied (units/acre), R_i is the unit price of input i (\$/unit), ΔAOC is the change in annualized ownership costs for the sprayer and VRT equipment components (\$/acre), ΔSOC is the change in sprayer operating costs (\$/acre), and ΔINFO represents the change in information-gathering and other annual costs (\$/acre).

Annualized ownership costs (AOC) (\$/acre) for the self-propelled sprayer and selected set of VRT equipment components j were calculated as:

$$\mathrm{AOC} = \mathrm{NSS} \times \mathrm{PAS} \times \sum_{j=1}^{m} \frac{\mathrm{VRT_j}}{\mathrm{CA} + \mathrm{OA}}, \tag{2}$$

where NSS is the number of VRT-equipped self-propelled sprayers, PAS is the proportion of investment costs for equipment component j allocated to sprayer operations, VRT is the annualized cost of VRT equipment component j (\$/acre), CA is cotton area (acres), and OA is other crop area (acres). PAS allows for equipment investment costs to be allocated across multiple production decisions, such as planting, fertilization, or yield monitoring, that are performed in addition to sprayer application of chemicals. In the case where a VRT system component is used exclusively for variable rate application of sprayer-applied inputs, PAS is set to equal one. CA and OA allow equipment ownership costs to be allocated across total crop area. If a component is assumed to be used only for the cotton enterprise, OA is set equal to zero.

Annualized ownership costs for the individual VRT components from Eq. (2) were calculated using standard capital budgeting methods (AAEA, 2000; Boehlje and Eidman, 1984):

$$\mathrm{VRT}_j = (\mathrm{PT}_j - \mathrm{SV}_j) \times \mathrm{CR} + \mathrm{SV}_j \times \mathrm{IR} + \mathrm{PT}_j \times \mathrm{TIH} \quad (3)$$

where PT is the purchase price of VRT equipment component j ($), SV is the salvage value of VRT equipment component j ($), CR is the capital recovery factor (%), IR is the discount rate representing the opportunity cost of capital (%), and TIH is the percentage of purchase price used to calculate taxes, insurance, and housing costs (%). The capital service cost annuity [(PT - SV) × CR] represents the opportunity cost of capital (interest) and the loss in equipment value (depreciation) due to wear, obsolescence, and age (AAEA, 2000). CR was calculated as [$\mathrm{CR} = \mathrm{IR} / (1 - (1 + \mathrm{IR})^{-T}$], where T is the estimated useful lifetime of equipment in years (Boehlje and Eidman, 1984). The second term [SV × IR] represents an interest charge on any projected equipment salvage value. The last term [PT × TIH] represents annual taxes, insurance, and housing costs ($).

VRT Investment Payback Variables

Potential payback variables for VRT systems included input savings, yield gains, and reduced application costs. As specified in Eq. (1), a reduction in the quantity of inputs applied (i.e. $\Delta X_i < 0$) will have a positive effect on net return. When such savings are sufficient to offset any increase in equipment ownership and information-gathering costs, the change in net return is positive and the VRT investment decision will be profitable. In contrast, if input cost-savings from VRT adoption are less than VRT equipment and information-gathering costs, the change in net return is negative and the VRT investment is unprofitable. Adjustments to the quantity of inputs applied may also affect yield, and therefore net returns. For example, VRT may provide yield gains in areas of the field where field-average application rates were suboptimal.

When combined with other precision agriculture technologies, VRT has the potential to further improve farm profitability through reduced equipment and application costs. For example, automated guidance or real-time kinematic (RTK) systems may lower sprayer-related ownership and operating costs through increased field speed or reduced boom overlap during swathing (Buick and White, 1999; Ehsani, Sullivan, and Zimmerman, 2002; Griffen, Lambert, and Lowenberg DeBoer, 2005). Automatic boom control may also lower chemical and application costs by reducing off-field application errors (Batte and Ehsani, 2006).

The change in sprayer operating cost (ΔSOC) ($/acre) due to an increase in field speed or a reduction in boom overlap was calculated as,

$$\Delta SOC_i = \frac{W + CFL + CRM}{\Delta SFP_i} \quad . \tag{4}$$

where W is operator wage ($/hour), CFL is the cost of fuel and lubricants ($/hour), CRM is repair and maintenance ($/hour), and ΔSFP is the change in sprayer field performance (acres/hour). Because the numerator in Eq. (2) is a constant, any change in ΔSOC is a direct function of ΔSFP. An increase in SFP decreases SOC, whereas a decrease in SFP has the opposite effect. Traditionally, ΔSFP is modeled as function of boom width (BW), field speed (FS), and field efficiency (FE). In such cases, boom overlap that might occur during parallel swathing is incorporated into the expected FE values. Here, we explicitly model ΔSFP as a function of field speed and boom overlap,

$$\Delta\text{SFP} = \frac{\text{BW}(1-\text{BO}_{\text{URT}})\times\Delta\text{FS}\times\text{FE}}{8.25} - \frac{\text{BW}(1-\Delta\text{BO})\times\text{FS}_{\text{URT}}\times\text{FE}}{8.25}\ , \qquad (5)$$

where BW is boom width (feet), BO is boom overlap as a proportion of total boom length (0-1), ΔBO is the change in boom overlap as a proportion of total boom length (0-1), FS is field speed (miles/hour), FE is field efficiency with full utilization, and the subscript URT denotes when baseline URT values should be used in calculating ΔSFP values. The first term allows for an increase in SFP through an increase in field speed. The second term allows for an increase in SFP through a decrease in boom overlap. If there is no change in FS or BO, then ΔSOC in Eq. (4) becomes zero and drops out of the net return equation.

Example Investment Decision Analyses

Example 1: Ownership Cost Calculation

In the first example, we use the partial budget framework to evaluate equipment ownership and information costs for map- and sensor-based VRT systems when the information is not used for a specific VRT decision. The representative farm used was a medium-sized West Tennessee cotton farm with 900 cotton acres and 1000 other crop acres (Tiller and Brown, 2002). VRT equipment prices represent the average price from an informal survey of equipment providers. A variable rate controller/monitor was $6,000, the GPS receiver and antenna was $5,000, a personal home computer with GIS software was $1,450, and a charge of $500 was assumed for installation. Components were assigned a useful life of 10 years; and annual taxes, insurance, and equipment storage costs were valued at 2% of purchase price. Eighty-percent of VRT equipment and information costs to the sprayer under the assumption that VRT components and any information gathered were used to conduct precision agriculture tasks other than application. Likewise, 80%

of equipment and information costs were allocated to cotton acres based on the typical number of passes over the field for cotton versus alternative row crops (Gerloff, 2008).

The map-based system was assumed to utilize Normalized Difference Vegetative Index (NDVI) data acquired via an aerial imagery service provider at a cost of $9.00/acre for a multiple fly-over service (Robinson, 2004). Additional information costs $800/year for access to a GPS signal network, $1.00/acre for custom prescription map making, $250/year for GIS software maintenance, $700/year for data analysis and training, and 10 hours of on-farm labor not normally incurred with URT (10 hours). The additional labor was valued at $8.50/hr (Gerloff, 2008). Annual fees for field scouting were assumed constant between URT and VRT scenarios.

The sensor-based system was assumed to collect spatial NDVI data using sensors mounted on a self-propelled sprayer with a 60-ft boom. Systems differed in cost depending on the number of sensors used for making input decisions. Systems with more sensors had higher resolution and were more costly, but also potentially provided greater input savings. Here, we evaluate two levels of sensor resolution: (i) a system of six sensors that provides input recommendations at a 30 ft × 20 ft resolution level priced at $15,000, and (ii) a 30-sensor system providing resolution at a 2 ft × 2 ft level priced at $60,000 (Solie, 2005). Sensors were treated as capital goods and costs were annualized using Eq. (2) and (3). In contrast with the map-based method, the sensor-based method did not include costs for a spatial data subscription service or for custom mapping. All other information costs were assumed identical to the map-based VRT.

Example 2: Medium-Sized West Tennessee Cotton Farm

In the second example, we use the same representative farm to evaluate the profitability of map- and sensor-based VRT systems at 5%, 10%, and 15% levels of input savings. We assume an 850 lb/acre average yield with a lint price of $0.68/lb for cotton produced in no-till with Bollgard II

Roundup Ready seed (Gerloff, 2008). Input costs used were based on extension recommended input rates found in the 2008 University of Tennessee-Extension's Crop Production Budget (Gerloff, 2008). A total of nine passes over the field was assumed; including one pre-plant herbicide application, four post-planting herbicide applications, one insecticide application, two growth regulator applications, and one defoliant and boll opener application before harvest. Baseline chemical costs for sprayer-applied inputs were \$62.46/acre for herbicide applications, \$29.00/acre for insecticides, \$5.10/acre for growth regulator, and \$6.60/acre for boll openers and chemical defoliants. No increase in field speed or decrease in boom overlap was assumed.

Results

Example 1: Ownership Cost Calculation

Total per-acre equipment ownership and information costs were \$10.97/acre for the map-based VRT system and \$4.79/acre and \$10.25/acre for the low- and high-resolution sensor-based VRT systems, respectively (Figure 1). Despite the similarity in total per-acre cost for the map-based and high resolution sensor-based systems, the cost structure differed significantly. The map-based VRT system had high information-gathering costs but low equipment ownership costs. In contrast, the high-resolution sensor-based VRT system had low information-gathering costs but high equipment ownership costs.

The difference in per-acre cost estimates between VRT systems is primarily due to the cost of spatial data collection (Table 1). Ownership costs for the NDVI sensors were \$1.82/acre for the low-resolution kit (20 ft × 30 ft) and \$7.28/acre for the high-resolution kit (2 ft × 2ft). The cost for the high-resolution kit was almost identical to the \$7.20/acre aerial imaging cost that was obtained by allocating 80% of its total initial cost (\$9/acre) to sprayer operations. Annualized ownership costs for the variable rate controller-monitor, GPS, and GIS components are assumed identical regardless of VRT system, for a total cost of $1.56/acre. Similarly, annual information costs for the GPS signal subscription, GIS software maintenance, prescription map making, data analysis and training, and labor costs are also assumed identical for all VRT systems for a total cost of $2.43/acre.

These results highlight the distinguishing characteristics of the two VRT systems analyzed. Sensor-based systems require a substantial initial investment, but have low recurring annual costs compared to aerial imaging-based systems. The total initial investment cost for sensor-based systems was $72,950, which included the high-resolution NDVI sensor kit, variable rate controller, GPS and GIS components; as compared to $12,950 for the aerial imaging-based system which had identical equipment except for the NDVI sensors.

Example 2: Medium-Sized West Tennessee Cotton Farm

The profitability of the two VRT systems analyzed varied based on the inputs varied and the level of input savings (Table 2). Considering all sprayer-applied inputs used in cotton production, results indicated that a 10% level of input cost savings would not be sufficient to pay for VRT systems utilizing aerial imaging or high-resolution sensors for information-gathering. In both cases, the breakeven input cost savings is 11%. At a 15% input cost savings level, the adoption of a VRT system would increase profitability by $4.29/acre using aerial imaging and by $4.21/acre using high-resolution sensors. Considering the variable rate application of herbicides only, cost savings of over 15% would be required to pay for the VRT system utilizing aerial imaging or high-resolution sensor kits. The breakeven herbicide cost savings were 18% for aerial imaging and 19% for the high-resolution sensors. A 10% level of input savings, however, would pay for investments in low-resolution sensor kits and would increase profitability by $4.51/acre.

The profitability of VRT systems using high-resolution sensor kits for information-gathering was the most sensitive to the cotton area planted and equipment lifetime (Figure 2). A cotton area of 600 acres or less, or an equipment lifetime of 5 years or less would result in VRT investments being unprofitable. This is not surprising due to the large initial investment required for sensor-based VRT systems. Larger cotton areas or longer useful equipment lifetimes allow fixed costs to be spread across more acres. An allocation of 100% of costs to the sprayer, or an increase in the price of the sensor kit to $80,000 would result in positive but much smaller net returns as compared to the baseline scenario. Net returns were also sensitive to interest rate, VRT annual costs, and VRT equipment costs, but net returns remained positive even at low values.

The profitability of VRT systems using aerial imaging was the most sensitive to sprayer cost allocation, but the change in net returns remained positive across the entire range of values considered (Figure 3). As compared to sensor-based VRT investments, VRT investments using aerial imagery for information-gathering were less sensitive to changes in cotton area and aerial imagery costs. For example, even with aerial imaging fees of $12/acre or a farm size of 600 acres, net returns remain above $2/acre. VRT equipment costs, VRT annual costs, and interest rate had only a small effect on net returns to cotton production.

Research Summary and Discussion

This paper analyzed the returns required to pay for investments in map- and sensor-based VRT systems for agricultural sprayers. Two commercially-available VRT systems, one using aerial imaging and the other using vehicle-mounted sensors, were considered in detail. The profitability of each system was determined by comparing potential input and application cost savings with annualized ownership and annual information-gathering costs. The framework was illustrated using example analyses based on a medium-sized cotton farm in West Tennessee.

Sensor-based VRT systems were found to have high ownership costs but low recurring annual costs. In contrast, map-based VRT systems were found to have lower ownership costs but higher annual information costs. Under a baseline scenario, VRT systems using high-resolution NDIV sensors and those using aerial NDVI imagery were found to be become profitable at input savings levels of 11% or above. The profitability of sensor-based VRT systems was most sensitive to cotton area planted and the expected useful lifetime of VRT equipment. Increased cotton area or equipment lifetime allows these fixed costs to be spread across more acres. Producers with less cotton area, or who expect to use and maintain VRT equipment for fewer years may find aerial imagery VRT options more attractive.

Another key parameter to consider is the proportion of VRT ownership costs and information-gathering costs to be allocated to sprayer operations. Sensitivity analyses indicated that when VRT costs are allocated entirely to sprayer operations, the breakeven level of input savings required for VRT to pay increased significantly. A producer or custom applicator who is able to use VRT equipment components and site-specific data for precision agriculture tasks that are in addition to sprayer operations, such as planting, fertilization, and yield monitoring, would find VRT systems for agricultural sprayers to be more profitable.

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Table 1. Per-Acre Costs for VRT Equipment and Information-Gathering

Item	Unit	Quantity	Purchase Price	Per-Acre Cost
			$/unit	$/acre
VRT equipment costs (Annualized)				
Variable rate controller-monitor	item	1	$6,000	$0.73
GPS receiver and antenna	item	1	$5,000	$0.61
Computer and GIS software	item	1	$1,450	$0.18
Installation	item	1	$500	$0.04
NDVI sensor kit (20 x 30 ft resolution)	item	1	$15,000	$1.82
NDVI sensor kit (2 ft x 2 ft resolution)	item	1	$60,000	$7.28
VRT information gathering costs				
NDVI aerial imaging subscription	acre	900	$9.00	$7.20
GPS signal subscription fee	item	1	$800	$0.71
GIS software maintenance fee	item	1	$200	$0.22
Prescription map making	acre	900	$1.00	$0.80
Data analysis and training	item	1	$700	$0.62
VRT labor costs	hours	10	$8.50	$0.08

Table 2. Change in Net Returns ($/acre)

Information-Gathering Method	Level of Input Savings 10%	15%	20%
Aerial Imaging			
All Inputs	-$0.87	$4.29	$9.44
Herbicides Only	-$4.94	-$1.82	$1.30
High Resolution Sensor Kit			
All Inputs	-$0.95	$4.21	$9.36
Herbicides Only	-$5.02	-$1.90	$1.22
Low Resolution Sensor Kit			
All Inputs	$4.51	$9.67	$14.82
Herbicides Only	$0.44	$3.56	$6.68

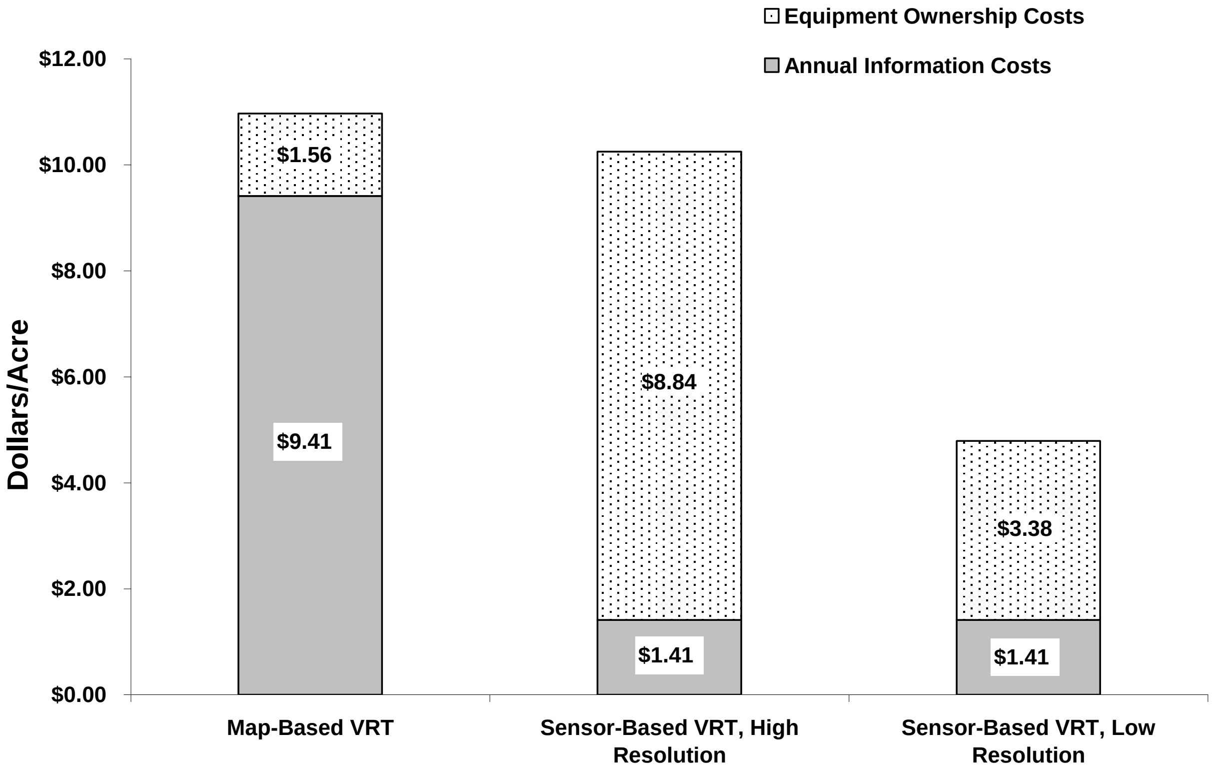

Figure 1. Summary of equipment ownership and annual information costs for map- and sensor-based VRT systems for a representative Tennessee cotton farm.

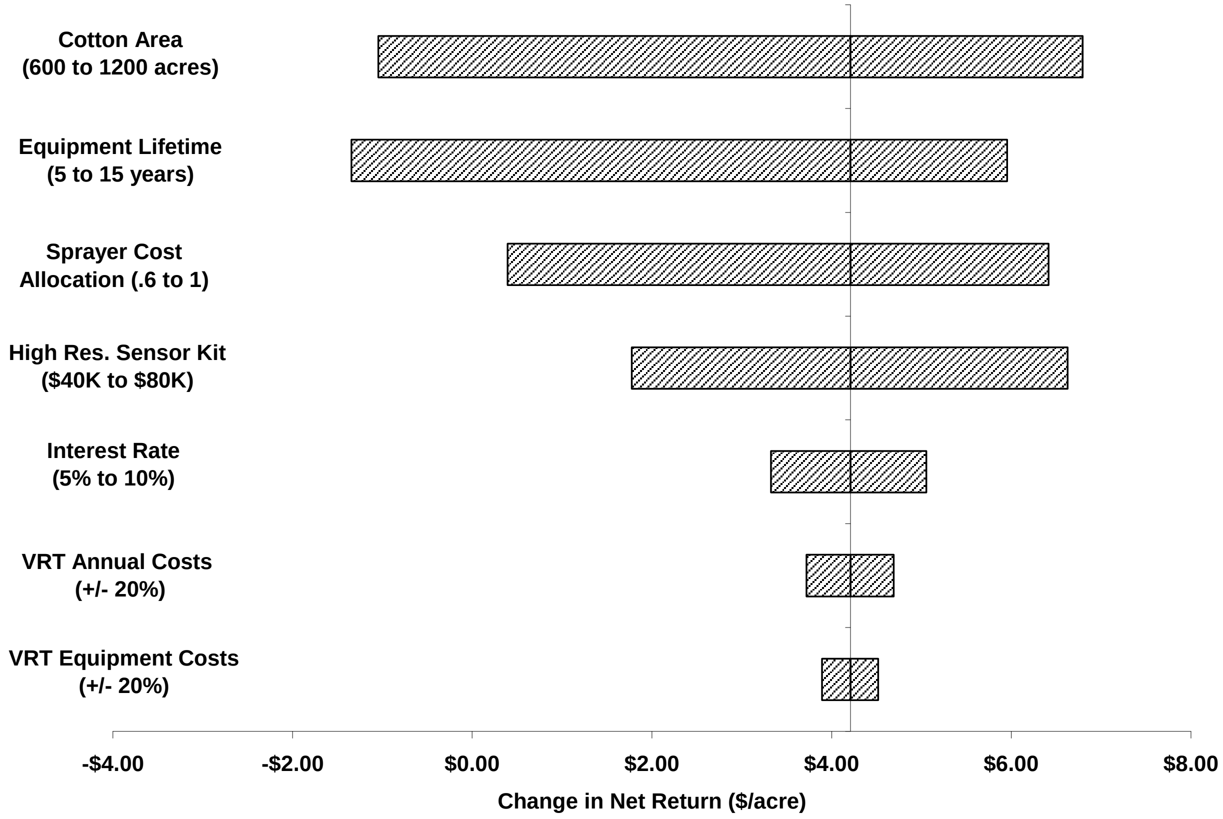

Figure 2. Sensitivity of VRT Net Returns to Key Parameters at a 15% Input Savings, NDVI High-Resolution Sensor Kit

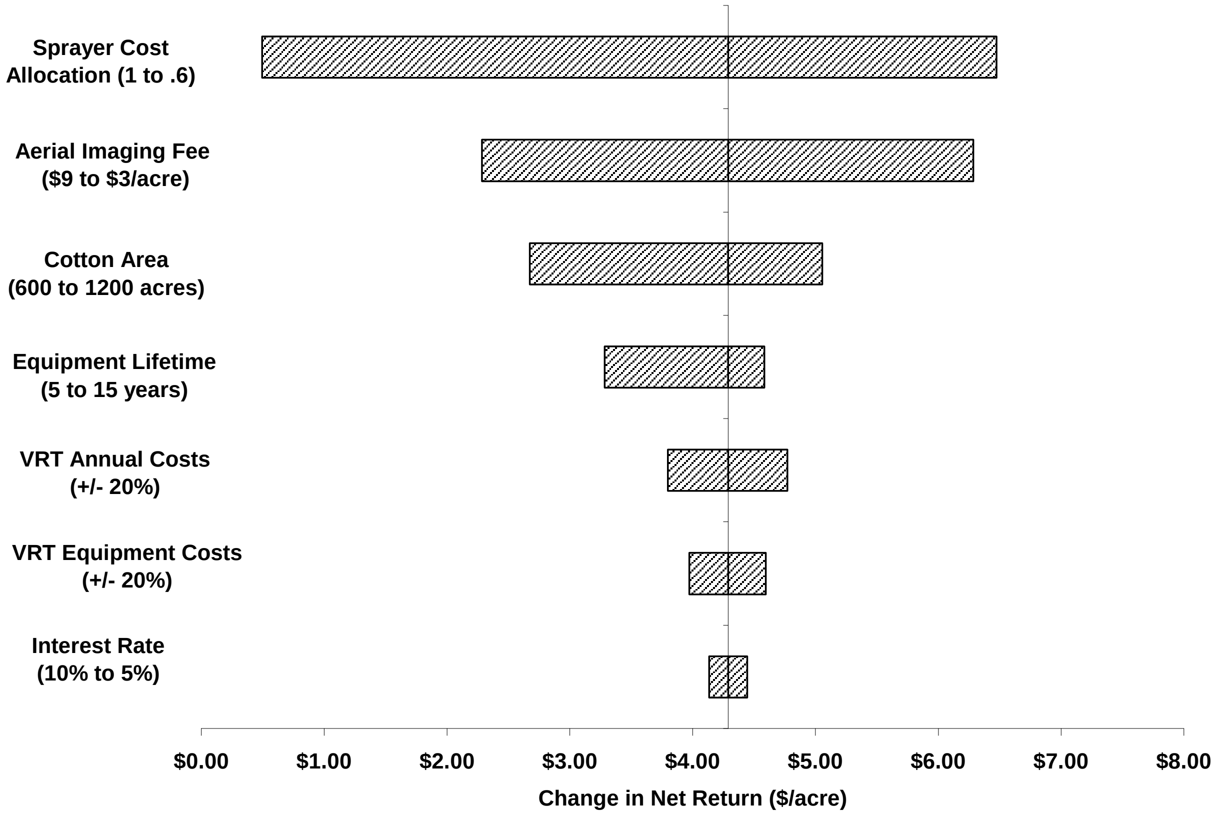

Figure 3. Sensitivity of VRT Net Returns to Key Parameter Values at 15% Input Savings, NDVI Aerial Imaging