When Does Variable Rate Technology for Agricultural Sprayers Pay? A Case Study for Cotton Production in Tennessee

By Daniel F. Mooney, James A. Larson, Roland K. Roberts and Burton C. English

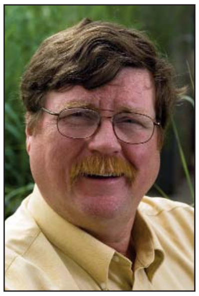
Abstract

Producers interested in precision agriculture lack information on the profitability of variable rate technology (VRT) systems for agricultural sprayers. A partial budgeting framework was developed to evaluate the level of input savings required to pay for investments in VRT. To illustrate this framework, a case study for cotton production in Tennessee is provided. Ownership and information costs were determined for two commercially-available VRT systems and compared to extension recommended input application levels. Map-based VRT systems required input savings of 11 percent to be profitable. Sensor-based systems required input savings from 5 to 11 percent to be profitable depending on imagery resolution.

Agricultural producers face a multitude of pre- and post-emergence input application decisions, including herbicides, insecticides, plant growth regulators and harvest aids. Many of these inputs are applied on a repetitive basis, resulting in multiple trips across the field and increased chemical, labor and application costs. Variable rate technology (VRT) for self-propelled, boom-type agricultural sprayers may reduce these chemical and application costs. A VRT system is a package of precision agriculture technologies that are used jointly to: (i) measure the spatial variability of input needs within a farm field; (ii) prescribe site-specific application rates that match varying crop needs; and (iii) apply those inputs as prescribed (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.

VRT has the potential to lower production costs and improve farm profitability by avoiding unnecessary input use. The actual level of input savings realized 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). Spatial variability is defined here as the distribution of distinct management zones within a field for which the yield response to a particular input varies (English, Roberts and Mahajanashetti, 2001). 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.



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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). Many of these studies however, overlooked key equipment ownership and information-gathering costs such as data acquisition, development of treatment maps, computer and data analysis training and additional labor (Griffin et al., 2004; Lambert and Lowenberg-DeBoer, 2001; Swinton and Lowenberg-DeBoer, 1998). As a result, they provide little guidance to those interested in investing in a VRT system.

Research Objective

The objective of this study is to provide farm managers and custom applicators with a framework for evaluating investments in VRT systems for agricultural sprayers. We achieve this objective through (i) identifying the capital ownership and information-gathering costs associated with VRT systems; (ii) developing a partial budgeting framework to determine the level of input savings required to pay for VRT investments; and (iii) illustrating the framework with a case study for cotton production in Tennessee. While the illustration emphasizes cotton production, the framework is easily extended to VRT systems designed for other crops and for other inputs. The framework will also be useful for evaluating future VRT systems as they become commercially available.

VRT Ownership and Information Costs for Agricultural Sprayers

Two methods currently used to gather site-specific crop information and variably apply inputs are map-based VRT and sensor-based VRT (Ess, Morgan and Parsons, 2001). With map-based VRT, a producer must load a prescription application map onto the sprayer's variable rate controller/monitor. Such maps are generally custom made using geo-referenced aerial or satellite imagery of crop density and vigor and are analyzed by the producer using geographic information system (GIS) software and a personal computer. The variable rate controller/monitor on the sprayer is able to read these maps and continually adjust the level of input applied as the sprayer moves through the field. A global positioning system (GPS) mounted onto the sprayer is used to identify exact field locations.

Equipment ownership costs for map-based VRT systems include the initial investment required to purchase a variable rate controller/monitor, personal computer with GIS software and a GPS receiver and antenna, along with any increase in taxes, insurance and storage. VRT information-gathering costs include all costs incurred on an annual basis that are in excess of those costs normally incurred in URT. Spatial data on crop characteristics are typically obtained through an aerial or satellite imagery service provider for which a fee is charged on a per-acre basis depending on the number of fly-overs per growing season and level of imagery resolution. Other information costs include subscription to a GPS signal network, custom services for prescription application map making, data analysis and training, and scouting fees or on-farm labor beyond that normally incurred with URT. 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.

Sensor-based VRT methods use vehicle-mounted sensors to gather spatial data on crop characteristics. As compared to map-based methods, the use of sensors eliminates the need for an annual subscription service to a spatial data provider. Sensor-based methods of spatial data collection are frequently referred to as active remote sensing. This is because sensors embody their own artificial light source and can therefore operate in limited sunlight conditions – such as early dawn, late afternoon or on overcast days. By contrast, aerial or satellite imagery options are referred to as passive remote sensing and require daylight and relatively cloud-free skies to obtain data.

An additional benefit of sensor-based VRT systems is that spatial crop data can be analyzed in real time so that inputs can be applied on-the-go without the need for GPS or GIS system components. Indeed, Swinton (2005) indicated that on-the-go sensors have the most promising future among site-specific input management technologies because of the potential to cut information collection costs and timeliness problems with spatial data collection. Nonetheless, growers are likely to continue using sensor-based technologies in combination with GPS and GIS technologies to keep input application records for financial record-keeping or compliance purposes, to compare variations in input use across years, or to 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 use of such components likely for input application even when on-the-go application is possible.

Ownership costs for sensor-based VRT are higher than for map-based VRT, but annual information gathering costs are lower. To achieve both mapping and application capabilities with sensor-based VRT, producers must invest in a variable rate controller/monitor, GPS receiver and antenna and GIS software and a personal computer similar to map-based VRT. However, they must also purchase the sensors used for information gathering, resulting in a substantially larger initial investment cost for sensor-based VRT. This increased initial investment for sensor-based VRT relative to map-based VRT is partially offset by a reduction in annual fees paid to spatial data and custom mapping providers.

Partial Budgeting Framework

The partial budget equation used to analyze the level of input savings required to pay for map- and sensor-based VRT systems for sprayer-applied inputs was:

$$\Delta NR = \sum_{i=1}^{n}[(P\Delta Y_i - R_i\Delta X_i)] - AOC - INFO, \qquad (1)$$

where ΔNR is the change in net return ($/acre), P is lint price ($/lb), ΔY_i is the change in lint yield due to VRT input decision i (lbs/acre), ΔX_i is the change in crop input due to VRT input decision i (units/acre), R_i is the price of crop input X_i ($/unit), AOC represents annualized ownership costs of VRT equipment components ($/acre) and INFO represents annual information-gathering costs ($/acre). A reduction in the quantity of inputs applied (i.e., $\Delta X_i < 0$) will have a positive effect on net return. The breakeven level of input savings occurs at the point where such savings are just sufficient to completely offset VRT equipment ownership and information-gathering costs. If the level of input savings exceeds VRT ownership and information costs, then the change in net return is positive and the VRT investment decision will be profitable. In contrast, the VRT investment decision is unprofitable when input cost savings are less than VRT equipment and information costs and the change in net return is negative. The partial budgeting equation assumes the numbers of annual passes over the field with and without the VRT system are identical. It also assumes that adopting the VRT system has no impact on ownership or operating costs of the self-propelled sprayer itself.

The variable rate controller-monitor, GPS and GIS equipment components of the VRT systems are treated as a set of capital goods denoted by j. Annualized ownership costs ($/acre) for each component were calculated as:

$$AOC_j = NSS \times PAS_j \times \frac{VRT_j}{CA + OA}, \qquad (2)$$

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 each VRT component j in Equation (2) were calculated using standard capital budgeting methods (AAEA, 2000; Boehlje and Eidman, 1984):

$$VRT_j = (PT_j - SV_j) \times CR + SV_j \times IR + PT_j \times TIH \qquad (3)$$

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 [$CR = IR / (1 - (1 + IR)^{-T})$], where T is the estimated useful life of the investment 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 ($).

Case Study: Cotton Production in Tennessee

We applied the partial budgeting framework to cotton production in Tennessee. Results from a 2005 cotton precision farming survey conducted in Tennessee and 10 other southern states indicated that 39 percent of respondents had adopted some form of VRT (Roberts et al., 2006). Further increases in VRT adoption by cotton producers are constrained by a lack of information about equipment ownership and information-gathering costs and the returns needed to pay for such investments. An investment decision aid has previously been developed for the cotton yield monitor investment decision (Larson et al., 2005), but no comparable tool exists for VRT systems for sprayer-applied inputs.

VRT Equipment for Agricultural Sprayers

VRT equipment ownership and information gathering costs were estimated for a medium-sized representative cotton farm in West Tennessee with 900 cotton acres and 1000 other crop acres (Tiller and Brown, 2002). VRT equipment prices used in the analysis represent the average price from an informal survey of equipment providers. A variable rate controller/monitor is priced at $6,000; the GPS receiver and antenna are valued at $5,000, a personal home computer with GIS software is set at $1,450 and a charge of $500 was assumed for installation. Components were assigned a useful life of 10 years; annual taxes, insurance and equipment storage costs were valued at two percent of purchase price. We allocated 80 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, equipment and information costs were allocated to cotton acres at a rate of 80 percent based on the typical number of passes over the field for cotton versus alternative row crops (Gerloff, 2008).

VRT Information-Gathering Methods

Commercially-available information-gathering technologies were considered for both map- and sensor-based VRT systems. In both cases, spatial data for variable rate application are based on the Normalized Difference Vegetation Index (NDVI). NDVI data provide a numerical measure of plant density and vigor based on the reflectance of visible and near-infrared light from cropped land. Chlorophyll in healthy crop leaves absorbs visible light but strongly reflects near-infrared light. In contrast, unhealthy leaves and sparse vegetation reflect both visible and near-infrared light. NDVI sensors capable of measuring reflectance data then transform the data into index values that can be used to determine the appropriate application rate for a given input (Weier and Herring, 2008).

The map-based system was assumed to utilize spatial NDVI data acquired via an aerial imagery service provider at a cost of $9.00/acre for a multiple fly-over service customized to provide NDVI data specific to cotton production (Robinson, 2004). Additional information-gathering costs for the map-based system included access to a GPS signal network ($800/year), custom services for prescription application map making ($1.00/acre), GIS software maintenance ($250/year), data analysis and training ($700/year) and on-farm labor in excess of that normally incurred with URT (10 hours). The additional labor was valued at $8.50/hr (Gerloff, 2007). Annual fees for field scouting were assumed to remain 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 differ in cost depending on the number of sensors used for making input decisions. Systems with more sensors have higher resolution and are more costly, but also potentially provide greater input savings because input decisions are made based on smaller land surface areas. 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 Equations (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-gathering costs were assumed identical to the map-based system.

Input Savings

The level of input savings needed to pay for the VRT investment was determined by comparing annualized ownership and information-gathering costs with extension recommended input rates found in the 2008 University of Tennessee-Extension's Crop Production Budget (Gerloff, 2008). The budget assumed no-till cotton production with Bollgard II Roundup Ready stacked seed traits and an average yield of 850 lbs/acre (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. 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. Breakeven input savings values were determined for (i) all inputs combined and (ii) herbicides only.

Results

VRT Equipment and Information Costs

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.

A breakdown of equipment ownership and information-gathering costs for particular components is presented in Table 1. The difference in per-acre cost estimates between VRT systems is primarily due to the cost of spatial data collection. 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 percent 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 is $72,950, which includes the high-resolution NDVI sensor kit, variable rate controller, GPS and GIS components, as compared to $12,950 for the aerial imaging-based system with identical equipment except for the sensor kit.

Breakeven Input Savings

Breakeven levels of input savings were determined by comparing per-acre VRT costs with extension recommended input levels. The breakeven level of input savings for map-based VRT using NDVI aerial imaging data was 11 percent. This implies that a producer would need to realize average annual reductions of 11 percent or greater across all sprayer-applied inputs for the lifetime of the VRT equipment to make map-based VRT pay for the representative medium-sized Tennessee cotton farm described above. For sensor-based VRT systems, comparable breakeven input savings levels for low- and high-resolution NDVI sensors are 5 percent and 11 percent, respectively. In the case where only herbicide input costs are considered, the breakeven levels of input savings become 18 percent for map-based VRT, and 8 percent and 17 percent for low- and high-resolution sensor-based VRT, respectively.

Sensitivity analysis was performed to explore how changes in key parameter values affect breakeven savings level for all inputs. Parameters included in the sensitivity analysis and the ranges of values considered are included in Table 2. Sensitivity analysis results are presented graphically as tornado diagrams in Figures 2 and 3. Tornado diagrams allow us to visually compare one-way sensitivity analyses for multiple variables and determine which parameter values have the largest impact (Clemen and Reilly, 2001). The vertical line indicates the breakeven input savings level when parameters are held at their initial values as described in the case study. The horizontal bars indicate how the breakeven level of input savings change as parameter values are increased from their lower to upper bound.

The breakeven level of input savings for VRT systems using high-resolution NDVI sensors 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 five years or less would result in breakeven input savings levels above 15 percent. 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 increase in cotton area farmed to 1200 acres, a decrease in the proportion of costs allocated to sprayer operations to 60 percent or a reduction in the cost of NDVI sensors to $40,000 all resulted in breakeven levels of input savings below 8 percent (Figure 2).

The breakeven level of input savings for map-based VRT systems using aerial NDVI imaging was the most sensitive to sprayer cost allocation (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 (Figure 3). Breakeven input levels for both map- and sensor-based VRT systems were also sensitive to interest rate, annual information costs and VRT equipment costs but to a lesser extent (Figures 2 and 3).

Research Summary and Discussion

This paper analyzed the level of input savings 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 cost savings with annualized ownership and annual information-gathering costs. The framework was illustrated in a case study for 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 NDVI sensors and those using aerial NDVI imagery were found to become profitable at input savings levels of 11 percent or above.

Advantages of the sensor-based VRT system include the ability to obtain NDVI data as needed, including when operating on overcast days or during early morning or late evening hours. Aerial imagery options rely on an outside data provider and require clear days for operation, which may result in a delay between when data is needed and when it becomes available. When choosing which system to invest in, producers must weigh this perceived advantage with the large investment cost of sensor-based VRT systems. Due to these costs, the profitability of sensor-based VRT systems is sensitive to the cotton area planted and the expected useful lifetime of VRT equipment. Increased cotton area or equipment lifetimes allow 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.

While this study provides insight into the tradeoff between input costs savings and VRT equipment and information-collection costs, additional information is needed. Producers often adopt VRT for agricultural sprayers jointly with other precision agriculture technologies such as automated guidance or automatic boom control. These technologies may provide additional benefits such as reduced overlap during swathing, reduced off-field spraying of agricultural chemicals and increased field speed. Future research should consider how these additional potential benefits may also influence the profitability of VRT systems for agricultural sprayers.

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Table 1. Summary of equipment ownership and information-gathering costs for map- and sensor-based VRT for a representative West Tennessee cotton farm

Item	Unit	Quantity	Purchase Price	Per-Acre Cost
			$/unit	$/acre
Equipment ownership 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
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. Range of parameter values used for sensitivity analysis on the breakeven level of input savings

Variable	Base Value	Lower Bound	Upper Bound
NDVI aerial imaging fee ($/acre)	$9.00	$6.00	$12.00
NDVI high-resolution sensors ($)	$60,000	$40,000	$80,000
VRT equipment costs ($/acre)[1]	$1.56	$1.25	$1.87
VRT information costs ($/acre)[2]	$2.43	$1.94	$2.92
Equipment lifetime (years)	10	5	15
Sprayer cost allocation (proportion)	1.0	0.6	1.0
Cotton area (acres)	900	600	1200
Interest rate (%)	7.5	5.0	10.0

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[1] Includes the variable rate controller-monitor, GIS and personal computer, GPS, and installation.

[2] Includes the GPS signal subscription, GIS software maintenance, prescription map making (map-based VRT only), data analysis and training, and additional labor costs.

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

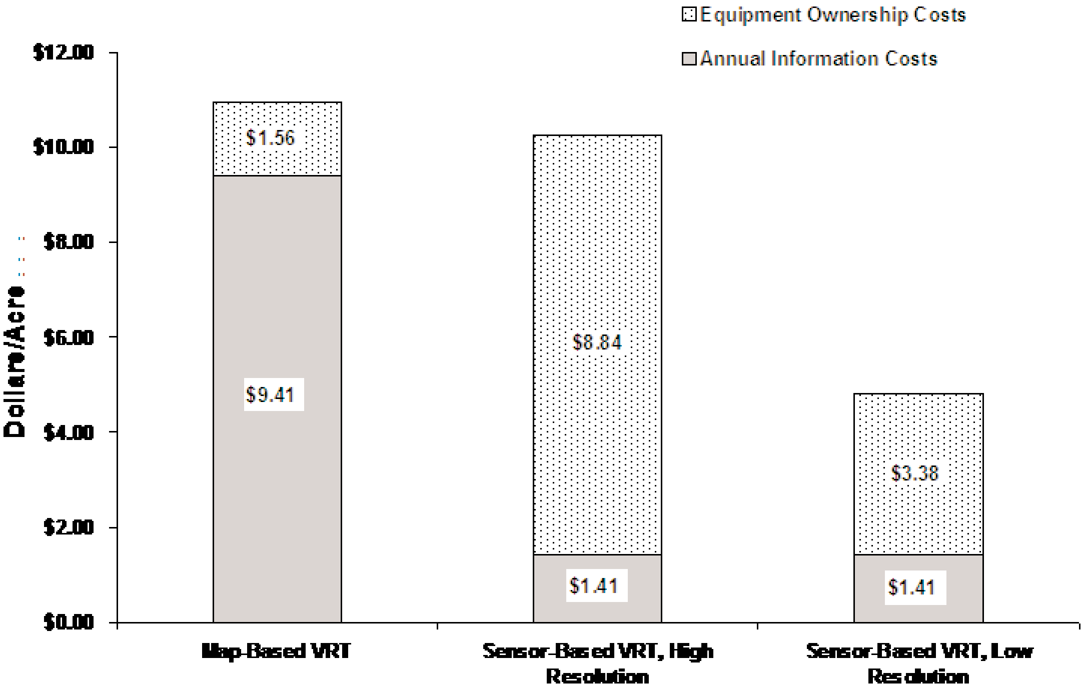

Figure 2. Sensitivity of breakeven input savings required to pay for investments in sensor-based VRT for a representative Tennessee cotton farm. Note: NDVI sensor costs are for the high-resoultion (2 ft x 2 ft) sensor kit

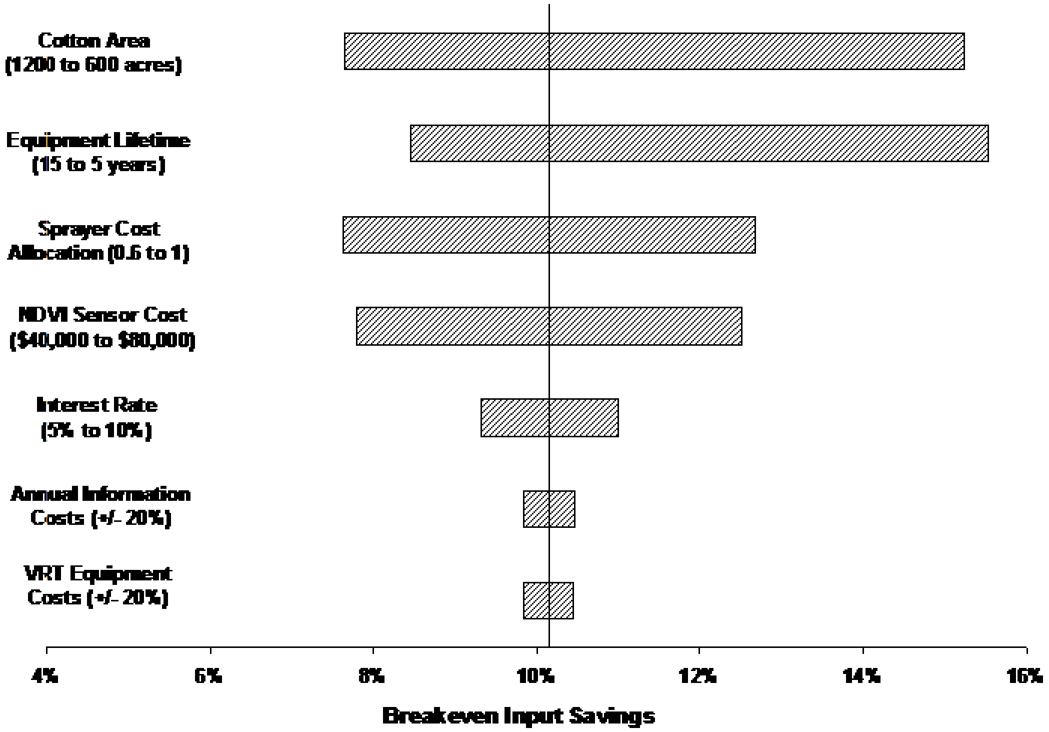

Figure 3. Sensitivity of breakeven input savings required to pay for investments in map-based VRT for a representative Tennessee cotton farm