THESIS

DESCRIBING AND QUANTIFYING REVENUE RISK PRODUCERS FACE WHEN ADOPTING WATER CONSERVING CROPPING SYSTEMS

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ABSTRACT

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Demand for water in Colorado is increasing rapidly due to the growth of population along the Front Range. Water resources in Colorado are mostly allocated with majority of the water being diverted for agricultural uses. Thus, in order to meet increasing municipal and industrial demand, water must be reallocated from agricultural uses. One way to reallocate water is for farmers to lease water rather than produce crops. This implies a change in production practices for the formerly irrigated cropland, and adaptations may include dryland cropping or fallowing. When water leasing is introduced, and production practices are adjusted, the profit risk that a farm business faces from uncertain yields and prices is affected.. This research examines four alternative cropping systems that producer may choose when seeking to conserve water and compares these to the two baseline cases of representing irrigated cropping systems. The research focuses on Weld and Logan counties of Colorado within the South Platte River Basin. The results are aimed to inform producers, researchers, water engineers and other stakeholders in order to make better water management decisions. A historical simulation method is used to quantify the difference in profits between the baseline cases and the alternative cropping systems. Results suggest foregone profits have the lowest mean and smallest distribution when switching from a fully irrigated corn rotation to a 2/3 irrigated corn and 1/3 fallow rotation. Results suggest a potential minimum level of payment for water leases.

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CHAPTER 1: INTRODUCTION

Colorado's water is a scarce resource with uncertain future supplies and increasing future demands. As an example, Colorado's state demography office forecasts a 56.8% increase in population by 2040 from the 2010 population base. These new households will need many resources including land, energy and importantly, water. Nearly all of Colorado's water resources are fully appropriated and utilized, so no "new" water is readily available. While conservation by households will become increasingly important, continued growth in municipal and industrial (M&I) water demands will undoubtedly require reallocating water from agriculture to M&I uses.

When shifting water from an agricultural to an M&I use, conventional practice is a permanent transfer of the water right accompanied by the fallowing or dry-land conversion of the formerly irrigated land. Fallowing ensures that all water associated with the purchased water right has been taken out of production, thus reducing monitoring costs. When widely adopted, these "buy-and-dry" transactions may have significant impacts on the agricultural sector and rural economies because of a direct loss of crop revenues and indirect loss of purchased inputs and spent wages in the area.

Few alternative water transfers to 'buy and dry' exist. One example is the purchase and lease back arrangements that the City of Thornton currently has with farms in Larimer and Weld counties, but these farms are expected to be fallowed in the future. As another example, the City of Aurora has leased water in order to fill reservoirs rather than completing an outright purchase in the Arkansas River Basin. However, traditional buy-and-dry water transfers dominate Colorado's previous agricultural to urban water transfers and seem likely in the future.

Since the early 2000's the state of Colorado has spent millions of dollars on programs identifying alternatives to permanent water transfers (Senate Bill 07-122). Alternatives included various forms of water leases in lieu of permanent transfers including rotational fallowing, limited irrigation and interruptible supply agreements. Decision tools have been created to help irrigators and policy makers understand the potential benefits of the various leasing alternatives. These decision tools are generally spreadsheet calculators that allow an irrigated farmer to compare alternatives based on assumed yields, prices and costs.

Risk is inherent in agriculture production. Farm managers must decide on the level of inputs to use well in advance of the realized harvest yield and prices. Indeed, prices and yields are almost always different than what was expected. This uncertainty gives rise to profit risk.

The aforementioned decision tools have not yet fully integrated yield and price risks into the complex decision environment faced by farmers who are choosing whether or not to participate in water leases. As an example, the decision tools do not specify the number of times that farm profits fall below average cropping profit or the number of times that a producer might fail to reach average profits when entering into a water leasing arrangement. In addition, these tools also fail to quantify the foregone benefits that accrue when irrigated farms' revenues are would have been greater than anticipated at lease signing.

Does entering into a water leasing arrangement exacerbate profit risk? Just as with decisions regarding agricultural inputs, water leasing decisions would also be made prior to planting. Producers may be reluctant to participate in water leases due to the lack of information on risk and return tradeoffs. Omitting this information understates the impact of risk on producer decision making and may undermine the success of water leases as alternative transfers to 'buy and dry' sales.

When offered an option of a leasing agreement, the producer's task becomes balancing the tradeoffs between risk and profitability. Excluding or misunderstanding the risk in the producers' problem would allow for the possibility of lower compensation levels or payments to be assigned for water in water leasing transactions. This would lead to an overall decrease in producer potential profits and as a result, lower utility to a producer.

Objective Statement

The overall research goal is to describe and quantify the profit variation derived from uncertain price and crop yields for a representative farm contemplating the tradeoffs between traditional cropping systems and water conserving cropping systems. In this case, cropping systems that conserve water are those that reduce the consumptive use at the farm – water conserved from reduced conveyance losses or application losses are not considered. Specific geographic reference is made to Weld and Logan counties of northeastern Colorado, areas in which water leasing is likely within the South Platte River Basin. These counties are different, however, in their productivity and geographical location-- Weld County is located upstream and Logan County being located downstream. In each of these locations, a representative cropping system is created as a benchmark and its profits under varying prices and yields recorded. Alternative cropping systems are posited, and their profits under the same price and yield conditions are recorded. These profit distributions are then compared and an opportunity cost measure of foregone profits calculated by subtracting alternative cropping profits from the benchmark profits. Specifically the research involves three objectives:

a) Quantifying profits of water conserving cropping systems vis a vis a benchmarked irrigated cropping system

b) Characterizing the distribution of profits for water conserving cropping systems vis a vis a fully irrigated, benchmark cropping system when prices and yields vary

c) Comparing the profit distributions of alternative cropping systems based on "risk efficiency" criteria

d) Quantifying the potentially foregone profits for a water lease as an opportunity

The results of this analysis are useful to:

- Producers making water leasing decisions by providing more knowledge and understanding of how uncertainties in prices and yields affect the profits of traditional and alternative cropping systems,

- Stakeholders looking to evaluate alternatives to historical agricultural water transfer programs such as buy-and-dry approach,
- Entities seeking to contract water resources from agricultural producers, and
- Researchers evaluating policy and predicting future behavior.

An Overview of the Methodology

In this research, the methodology begins by identifying a representative irrigated farm in the South Platte River Basin for Weld and Logan Counties in Colorado using standard techniques. A typical cropping system is established as the baseline cropping system. Alternative cropping systems are then identified, and these systems represent likely adaptations for the area. The modeling procedure involves collecting enterprise budgets for irrigated cropping systems and aggregating these to a farm systems level. Whole farm profits are calculated assuming the typical resources available to a representative farm in Colorado's South Platte River Basin.

Annual profits for the various cropping systems depend importantly on crop yields and prices. Indeed, a cropping system that performs relatively well under low prices and average yields may perform poorly when prices are high and yields are low. . The model developed in this thesis allows price and yields to vary. Model iterations result in a collection of profits resulting from variable price and yield conditions. These profit frequencies are compared and contrasted according to risk efficiency criteria that include evaluation of mean, variance, coefficient of variation, and cumulative distribution frequencies. The research results generate fundamental new knowledge related to the economics of irrigated cropping systems and water conserving opportunities in irrigated production sector.

Data

The yearly crop yield data are collected from United States Department of Agriculture (USDA) and National Agricultural Statistical Service (NASS) Quick Stats and published Annual Agricultural Statistical Reports. The price data are yearly harvest month averages from Greely Elevator obtained from Randy Hammerstrom Agricultural Marketing and News Service (AMS) Market Reporter, accessed January 2012. Seasonal net water requirement and effective precipitation is obtained from Colorado State University Extension Worksheet Number 4.718, authored in 2009 by Joel Schneekloth, regional water resource specialist with Colorado State University (CSU) Extension and Allan Andales, Assistant Professor is the Department of Soil and Crop Sciences. The cost data is obtained from the 2009 enterprise budgets published by the Colorado State University Extension. Altogether, county level data is obtained for 30 years total between 1980 and 2010.

Contribution of Study

As is discussed in the literature review in Chapter 2 of this thesis, current decision support systems do not incorporate price and yield uncertainty in their depiction of the tradeoffs to leasing irrigation water instead of cropping. The current analysis is a more realistic portrayal of the risks producers face in association with various cropping systems that serve as alternatives to fully irrigated production. The model can be utilized as an extension to an existing decision support system.

The distribution of profits and opportunity cost of foregone irrigation provides municipal, industrial and agricultural sectors signals one portion of the irrigator's valuation of water. These estimates will help water leasing institutions, such as the proposed Lower South Platte Cooperative, select, evaluate and predict participation in leasing arrangements. Ultimately such a risk enhanced model will increase understanding and help to better manage water-planning decisions.

Organization of Thesis

The thesis includes chapters in the following order; "Literature Review", "Methodology", "Analysis and Results", "Summary", and "Conclusions and Limitations". "Literature Review" contains a summary of previous research conducted in the area of water leasing and agricultural production risk. "Methodology" describes an analytical model and the resulting empirical methodology as well modeling strategies and procedures that are implemented. "Analysis and Results" section shows the outcomes of the model and describes the applicability of the results. "Summary" discusses implications of the research while “Conclusions and Limitations” wrap up the thesis with final thoughts, acknowledge the shortcomings of the research and provide suggestions for further studies

CHAPTER 2: LITERATURE REVIEW

The research objective of this thesis is to describe and quantify profit risks due to price and yield variation that producers face when evaluating water conserving cropping systems versus baseline, representative cropping systems. As a result, the following section introduces previous research in water leasing and water reallocation. Methodologies and simulation modeling strategies that are similar to the techniques used in this model are reviewed. In addition, this section of the thesis includes literature on water conservation strategies targeting the objective of maximizing the value of water. Lastly, this review describes strategies used by economists to describe and quantify risks particularly those that are associated with irrigated crop production. Differences between the existing literature and this research are noted where appropriate.

Optimization and Simulation Models

The economics literature contains many studies describing how irrigated cropping profits are influenced by price and yield variability. Previous studies have focused on the optimal timing and or scheduling of irrigation with uncertainty in weather using optimization models. Optimization studies include Bryant, Mjelde and Lacewell (1993) , Mannocchi and Mecarelli (1994) focusing on optimizing production or profit by changing the cropping mix. These optimization studies are particularly well suited for determining the number of acres to be allocated among crops, the amount of water to be applied, and the implicit value of an extra increment of water applied to a crop.

Yet, farmers are not marketing a marginal amount of water when entering a lease; they instead are changing an entire cropping system. As a result, the current study is not concerned with the optimal allocation of water per se, instead, the research seeks to characterize cropping profits under a variety of price and yield conditions so that entire profit distributions can be compared. In this case, an 'average' rather than marginal value of foregone water can be calculated.. Due to the practicality of the cropping systems, the research approach provides an opportunity to deliver relevant and meaningful results that can be easily applied to producers' practices and water management decisions.

Due to the physical limits, data deficiencies and time constraints, it is often impossible to create a study that exactly depicts optimal resource decision by farmers weighing the advantages and disadvantages of water leases. Scientists, including economists, use simulations to provide an accurate and relevant portrayal of these decisions. In order for the simulation process to be implemented, a model is developed representing important aspects of the decision process including appropriate biological, physical and social systems. Data are used as model inputs to generate outcomes representing real world consequences to resource decisions. Once the simulation process is established, results and conclusions with according limitations can be made about the real world system. Much research, including the current study, uses the simulation models to make statements and conclusions about real world situations.

Below are several examples of how this process is implemented within the study of water leasing and water reallocation.

Calatrace and Garrido (2005) hypothesized that trading and leasing within a water market reduces economic profit risk due to the variability in annual water supply. Calatrace and Garrido concluded that producer profits would increase during a period of water scarcity when water leasing markets are available. Additionally, a producer would have a lower probability of profits reaching their lowest levels under the water leasing or trading options. The authors reach their conclusion by simulating farm profits with deterministic profit functions and stochastic water supplies. Profit distributions for alternative cropping systems are quantified and compared. Results suggest that mean and median profits are always greater in a cropping system with a water market as opposed to no-trade situation. Perhaps more importantly, the standard deviation of profits significantly decreases for all operations when water trading is allowed. This study's unit of analysis is at a water market level, while the current research focuses on farm level assessment of profits and risks. Nonetheless, profits between different scenarios are compared similarly to the way it is done in this research by examining minimum, maximum values, mean and standard deviations.

In 2010, Fathelrahaman et. al conducted an economic and stochastic efficiency comparison of tillage systems. When comparing the various tillage systems, gross margin and profits distributions were simulated. Distributions were compared using mean, median, standard deviation, and stochastic efficiency with respect to a function (SERF) was conducted. Using SERF means that both risk neutral and risk averse comparisons can be made between distributions, whereas mean, median and standard deviation comparisons presume risk neutrality. The current research assumes a standard tillage system, but also generated profit distributions that are compared using criteria posited by Fathelrahaman et al.

The simulation process selected as the empirical methodology in this research allows to us arrive at sample size from which results and conclusions can be drawn. These results are based on historical data and the immediacy of the conclusions permits them to be readily available for use by stakeholders in decision making process.

Deficit Irrigation

An alternative to 'buy and dry' activity is to deficit irrigate a crop and lease conserved consumptive use to other entities. In this context, deficit irrigation is irrigating a crop at less than its optimal consumptive use requirements. Deficit irrigation is a form of consumptive use conservation that might also be used to generate beneficial environmental flows for riparian areas. While leases of this type have not been observed, several entities are examining their potential.

Deficit irrigation, also known as limited irrigation, is a research area that has been studied heavily in the last decade. The practice of deficit irrigation involves one of two methods: (1) maintaining the traditional number of irrigation applications but applying less amount of water per application, or (2) maintaining the traditional amount of water applied but decreasing the application frequency. Ganji et. al developed a stochastic model in 2006 to determine optimal weekly deficit irrigation scheduling. In

2011 DeJonge et. al studied effects of full and limited irrigation on corn in the South Platte river basin of northeastern Colorado with an objective to statistically differentiate between full and limited irrigation treatments. Neither of the previous studies were economic in nature, rather they focused on agricultural engineering and/or agronomic aspects of deficit irrigation.

In 2010 Grove and Oosthuizen developed an expected utility optimization model with the objective of evaluating deficit irrigation as a production alternative. They modeled multi-crop setting and incorporated production risk associated with deficit irrigation. Risk aversion values were used to quantify the impact on profitability under scarce water supply conditions. The result of the study concluded that "Although deficit irrigation increased the gross margins, the increase is unable to compensate for the loss in total gross margins due to reduced water allocation." Thus, the study concludes that producers would not choose to employ deficit irrigation methods willingly. In addition, the study attests that deficit irrigation will not conserve water if irrigated acres are increased and such an increase is a determining factor for the overall profitability of production. It should be noted that the authors did not consider a lease payment to farmers in exchange for the consumptive use conservation., This lease payment would be compensation for forgoing irrigation, an opportunity cost.

Deficit irrigation offers research based solution to water conservation in irrigated cropping. As a result of conservation, water is made available for other uses. However, challenges with implementation of this strategy limit its potential in the applied world. Monitoring the amount of water conserved or applied is an ambiguous and costly task.

Thus it remains one of the biggest challenges in making deficit irrigation a reliable and realistic method of water conservation. The current research, documented in this thesis, forgoes the idea of deficit irrigation and instead uses variety of cropping systems with different net water requirements to conserve water. The crops continue to be fully irrigated, however, due to the different consumptive use needs, some countable amount of water is conserved for reallocation. By selecting an approach that more closely resembles how producers and the institution would work given an opportunity or platform for water leasing, it is believed that the results and analysis of the study will provide relevant and realistic information to the stakeholders.

Risk

This study's purpose includes characterizing profit risk in alternative cropping systems. Yet, producers also face institutional, biological and environmental risks, and this has been the subject of economic inquiry. It is useful to consider how economists have chosen to measure and define risk because it guides the choice of risk measure in the current study.

According to the Economic Research Service (Harwood et. al, 1999), crop producers are most concerned with environmental and market related risks, specifically yield and price risks. Most producers have risk averse preferences (meaning that a farmer prefers to accept a more certain, but possibly lower payoff, rather than a higher payoff with greater uncertainty. Understanding the source of risk and uncertainty helps producers make more informed and thus better decisions in risky situations.

Strategies to manage profit risk in agriculture production include enterprise diversification, crop insurance, production contracting, hedging, and use of risk-reducing inputs. Enterprise diversification involves trading off between potential declines in profits due to a less expensive crop for a decrease in income variability. Thus, higher profits are traded for lowering the risk of obtaining lowest profits. This method sometimes is referred to as crop diversification. Crop insurance is another method utilized by famers to mitigate risk. The decision remains on whether or not to purchase insurance and if so, what level of coverage would be optimal to the producer in order to hedge against risk, yet not to overpay for the service. Yet another way to manage risk is production contracting. A production agreement is entered between the producer and the integrator. Management decisions in that case are handled by the integrator while production decision by the producer. Market access is guaranteed and thus the producer's production and profit risk is reduced. In addition to approaches above, irrigation has also played a key role in risk reduction in agriculture.

Historically, irrigation has been one of the most common strategies used by producers as the means to manage yield risk. Irrigation may also be viewed as the means for permitting crop production in geographic areas that otherwise might not be economically feasible. Thus, availability of water for irrigation has been instrumental to producers reducing risk associated with production. This research studies how removing a portion of water from the irrigated production for leasing by choosing alternative cropping system changes the producer's profit risk when compared with fully irrigated production.

Risk analysis is often used when comparing farm level marketing strategies (Tomek and Peterson, 2001), but very little literature considers risk assessment of fully irrigated cropping systems. The only two examples appear to be Karagiaannis et al. (2003) who examine irrigation efficiency using a stochastic production frontier of Greek crops, and Taylor et al. (1993) case study of irrigation in the Arkansas River Basin of Colorado. It should be noted that dryland cropping systems have been the subject of risk analysis (Elder, 2004a; Williams, 1988; Williams et al., 1990), but economic research in irrigation more often involves assessment of water pricing (Goodman and Howe, 1997; Shuck and Green, 2002) or allocative efficiency (Young et al., 1986), and technology adoption (Carey and Zilberman, 2002) rather than a comparison of cropping systems.

Several criteria are available for evaluating net return distributions including the expected values, value at risk (VaR), Sharpe ratio, stochastic dominance (Gloy and Baker, 2001), willingness to pay (Wang et al., 1998), and semi-variance (Turvey and Nayak, 2003). Risk assessment criteria used in these studies are also used in this thesis to draw conclusions about the various cropping system options.

Methods and theories of previous research contribute to the development of this study. The current study adds to this literature by integrating price and yield variation in farm level cropping systems that serve as alternatives to fully irrigated production. Profit distributions of the various systems are compared to deliver analysis

CHAPTER 3: METHODOLOGY

This research considers the financial tradeoffs that exist when adopting different cropping systems under uncertain price and yield conditions. These financial tradeoffs include differences in realized profits, the potential for losses when price and/or yields are low and the opportunity cost of unrealized financial gains. The focus of analysis is an irrigated farm manager's question: how does the underlying distribution of farm profits change when adopting a water conserving cropping system? The goal of the heuristic, analytical model developed in this chapter is to characterize a representative farm's profits when prices and yields are stochastically determined. The following section explains the analytical model and empirical procedure used to meet research objectives and is organized as follows: an irrigated farm manager's problem is characterized without risk, risk is then introduced via stochastic prices and yields, potentially forgone profits are calculated, data is described and the simulation procedure introduced.

Farm Manager's Problem without Risk

The farm manager's problem is to maximize profit by optimally choosing a set of inputs. Input decisions are made prior to planting; however, commodity market prices and crop yields are generally realized after harvest. The time lag between the production decision and time of sale allows for variability in yield and prices, and thus introduces uncertainty in expected profit. In order to set the context for the farm manager's problem, we begin with a deterministic profit equation as introduced by Hotelling in 1930, where we assume the yield and commodity prices are known:

(1) $$\boldsymbol{\pi = R - C}$$

Where π represents profit, R is revenue and C is cost. Revenues can be disaggregated into outputs and their associated prices:

(2) $$\boldsymbol{R = \sum p_j * q_j}$$

Where $j = 1 \ldots n$ for any given crop p_j is price and q_j is the output quantity for output j. The price and quantity are values which impact revenue. The cost of production is the product of input prices and quantities in the absence of fixed costs:

(3) $$\boldsymbol{C = \sum c_i * x_{ij}}$$

Where $i = 1 \ldots m$, for any given input and c_i and x_i are the prices and quantities of input i. Note that inputs are indexed by *j* indicating that the use of the input is also crop specific. In equation (3), crop inputs would include fuel, fertilizer, seed, herbicide, labor, hauling and irrigation costs.

The amount of crop produced, q_j, can be replaced with a production relationship, transforming the relevant inputs, $x_{i,j}$, into q_j . In this case

(4) $$\boldsymbol{q_j = F(w_j, z_{ij} \mid A)}$$

Where x_{ij} is separated into two vectors, w_j and z_{ij}. Here, w_j is the amount of water input associated with its j^{th} output measured on net consumptive use (CU) basis and z_{ij} are the amounts of all other inputs used in the production of the j^{th} output. A is an exogenous variable for a fixed number of acres in operation. Adjusting equation (3) by separating the costs x_{ij} into respective vectors w_j and z_{ij} and then substituting equation (2), (3) and (4) into equation (1), yields the following profit function:

(5) $$\boldsymbol{\pi(w_j) = \sum p_j * F(w_j, z_{ij} \mid A) - (c_w w_j + c_i z_{ij})}$$

Importantly, equation (5) treats prices and yields as deterministic. In reality, these variables are stochastic with expectations around the harvest prices and yields. Depending on the cropping system, the price and quantity of output will change, thus yielding a different profit in equivalent market and growing conditions. The uncertainty is incorporated in the following equation.

(6) $$\mathbf{E}\left[\boldsymbol{\pi}\left(\boldsymbol{w}_{j}\right)\right]=\sum \boldsymbol{E}\left[\boldsymbol{p}_{j}\right] * \boldsymbol{E}\left[\boldsymbol{F}\left(\boldsymbol{w}_{j}, \boldsymbol{z}_{ij} \mid \boldsymbol{A}\right)\right]-\left(\boldsymbol{c}_{w} \boldsymbol{w}_{j}+\boldsymbol{c}_{i} \boldsymbol{z}_{ij}\right)$$

This equation demonstrates that there is an expectation around values of crop prices and yields. These variables are no longer deterministic. Their variation contributes to the risk in profits faced by the producers. The yields are affected by variations in factors such as weather, pests, weeds, etc. while the commodity prices are driven by national and international markets. Both yields and prices are revealed after the initial production choices have been made. Thus the production decisions are only made based on the expectation around prices and yields based on previous years' information. Depending on the cropping system, prices and yields may vary more or less. For example, the percentage variation in yield of dry land crops is much greater than that of the same crop that is irrigated. Thus, the percentage variation in profit could increase significantly when a dryland crop replaces an irrigated crop. Ultimately, this is an empirical question.

As indicated by the use of the expectations operator in equation (6), the farm manager makes choices at the beginning of the cropping season when crop prices and yields are not known with certainty. The farm manager's choice includes their decision about a cropping system; that is, the farm manager seeks to choose a feasible mix of crops that meets the farm's financial objectives in generating profits and managing risk. Of concern are at least three financial criteria: the likelihood that cropping system will generate greater profits when compared others (e.g., stochastic dominance) under the same price and yield conditions, that the cropping system will avoid financial losses more frequently than the other cropping systems, and that the selected cropping system gives the greatest potential "windfall" profits when prices and yields are most favorable.

It is computationally difficult, if not impossible, to fully characterize the true distribution of profit outcomes for the cropping systems that might be used in equation 6; after all many complex interactions take place between local prices, national prices, local commodity yields and national commodity yields for all crops. The method proposed in this thesis is to calculate a frequency of profits for cropping systems under specific price and yield conditions that are representative of historical conditions. As mentioned in Chapter 2, this approach has drawbacks, but it does permit cropping systems to be compared on the basis of the three criteria mentioned previously.

Baseline cropping system profits, π^0, are compared to alternative systems, π^r, that have a conserved amount of consumptive use (CU) water. The manager prefers the system with the highest profits, ceteris parabis. However, different price conditions lead to different profit outcomes. So the calculation can be repeated under different conditions, and all relevant outcomes collected in a frequency. The π^0 frequency can be compared to the π^r frequency in several ways including according to the frequencies' means and variances, by using stochastic dominance in order to rank frequencies based on the cumulative distribution of profits, and the likelihood of occurrence above and below a profit level.

Potentially Forgone Profits

Once the profits for baseline and alternative cropping systems are calculated and collected via multiple iterations, the relative performance of these systems can be compared. Note that these outcomes are not a harvest profit realization; rather repeated calculations will represent the "potential" outcomes, and we can observe differences between these potential outcomes. For example, this research compares each cropping system according to the profit, amount of water removed from production and amount of land is either planted to dryland crop or is fallowed.

Calculating potential forgone profit simply involves subtracting the alternative cropping system profit from the baseline profit in an iteration. The difference in profits can then be characterized per amount of land removed from production, or per amount of water removed from production. Equation 7 illustrates this calculation

(7) $$\boldsymbol{K_r = \pi_r^0 - \pi_r^s}$$

Where π_r^0 is the calculated Baseline profit in iteration r, π_r^s is the alternative cropping system profit in each specific iteration r and K_r is the difference between the two profits. This difference is a measure of the opportunity cost of choosing one cropping system relative to another. In this case R represents the total number of iterations. The mean profit difference is calculated as:

(8) $$E\,[\,K_r] = \frac{\sum_1^r \pi_r^0 - \pi_r^s}{R}$$

To calculate the mean potential forgone profit per unit of consumptive use (CU) the following equation is used:

(9) $$[\,K_r]\; per\ acre\ foot\ CU = \frac{\frac{\sum_1^r \pi_r^0 - \pi_r^s}{R}}{CU^0 - CU^s}$$

Where CU^0 is the amount of CU used in production in the baseline cropping system and CU^s is the amount of CU used in the alternative copping system. A frequency of the potential forgone profits is generated by repeating the following calculation in all iterations:

(10) $$\frac{K_r}{CU^0 - CU^s} = \frac{\sum_1^r \pi_r^0 - \pi_r^s}{CU^0 - CU^s}$$

The comparison of the potentially forgone profits on a per unit CU basis enhances understanding of the forgone opportunity of the unit of water removed from production under different cropping systems.

Simulation Process

This section of the thesis links the analytical framework described in equations (6) through (10) to the empirical simulation process that generates profit frequencies for various cropping systems. These frequencies are compared using various risk criteria.

Two representative cropping systems (Figure1) are used as the baseline in this analysis. Baselines 1 and Baseline 2 consist of fully irrigated corn and 2/3 corn 1/3 irrigated alfalfa respectively. In the equations above, Baselines 1 and Baseline 2 profits are noted with π^0 and alternative cropping systems' profits are noted with π^r.

Figure 1: Baseline Cropping Systems

In the anticipation of a water lease, consumptive use of irrigation water would need to be reduced. In this analysis, reducing consumptive use takes the form of either fallowing cropland or planting a dryland crop. These cropping systems include the following:

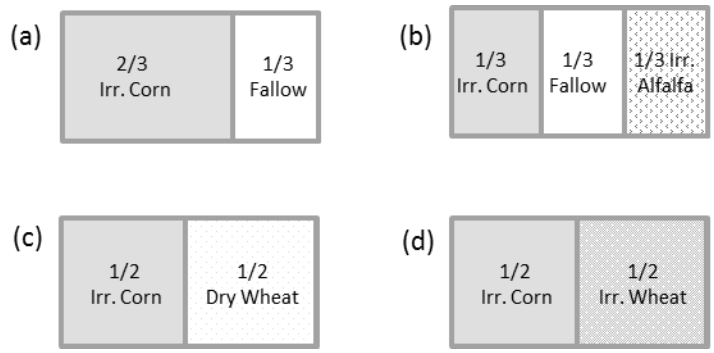

Figure 2: Alternative Cropping Systems

The cropping systems shown in Figure 2 are obtained using the expertise of Troy Bauder, an extension specialist, Neil Hansen, an associate professor of soil and crop sciences and James Pritchett, associate professor of agriculture economics at Colorado State University. (January, 2012). The systems represent likely adaptations of farmers who would seek cropping systems that conserve consumptive water use. They include crops that are typical to the area (corn, wheat and alfalfa) and require inputs that are readily available. This analysis treats the human capital used in irrigated agriculture versus dryland cropping to be fungible, when in fact some learning might need to take place by farm managers. Likewise, capital investments, such as hay harvesting equipment, are assumed to exist on the farm and be available for use. All of these resources are treated as slack resources. The expert recommendations were synthesized into 2000 acre representative farm systems.

Data

In order to calculate the profit as shown in equation (6), estimates of crop revenues and costs must first be obtained. Revenues require price and yield data. Costs include all variable costs involved in the on-farm production process. The data is collected from variety of sources described below.

The empirical method makes use of an historical bootstrapping procedure. Yearly yield data for each crop is collected at the county level from 1980-2010. Yearly irrigated and dry-land corn yields, irrigated and dry-land winter wheat yields, and irrigated and dry-land alfalfa hay yields are collected via United States Department of Agriculture (USDA) Quick Stats and Colorado Agricultural Statistical Service Publications.[1]

The price data for corn and wheat are acquired from the USDA Colorado Department of Agricultural Market and News Service from Greeley, Colorado with the help of Randy Hammerstrom, a market reporter (January, 2012). The price per bushel of corn is obtained using the averages of the prices in the month of November from 1981 to 2011. The price per bushel of winter wheat is obtained using the averages of the prices in the month of August from 1981 to 2010. The price for alfalfa hay per ton is given by the average of the prices in the month of July from 1990-2010. [2]

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[1] Data for dry alfalfa, years 1983-1986 and 2009-2010 for Weld, consists of average yields between 1980 and 2010 are used, as no data is available through USDA. The same method is followed for dry corn in 1988, 1990 and 2009 for Weld, and for irrigated wheat in 2010 for Weld.

[2] The 1980 price for corn and wheat is the Colorado state-wide average for the corresponding crop harvesting month. All prices are the average of multiple elevators within the area collected by USDA/AMS Livestock and Grain Market News. Alfalfa prices from 1980-1989 are recovered through the regression of Greely Elevator average July prices on the average statewide prices for July, obtained via USDA Quick

The table below shows a brief sample of irrigated corn data.

Table 1: Data Sample

Year	County	Irr Corn		Corn	GDP	Cost
		bu/acre	% e	$/bu	Ratio	2009 $
1980	Weld	114.00	-0.11	3.00	0.46	...442.6
1981	Weld	136.00	0.05	2.55	0.47	...442.6

In estimating profits, costs are deflated using a GDP index (not shown in the table).

An example model iteration is shown in Figure 3, and this describes how the raw data is randomly selected and farm profits calculated.

Stats. This method for recovering unpublished county level prices is justifiable by the correlation coefficient of state and local prices of 0.967.

Simulation

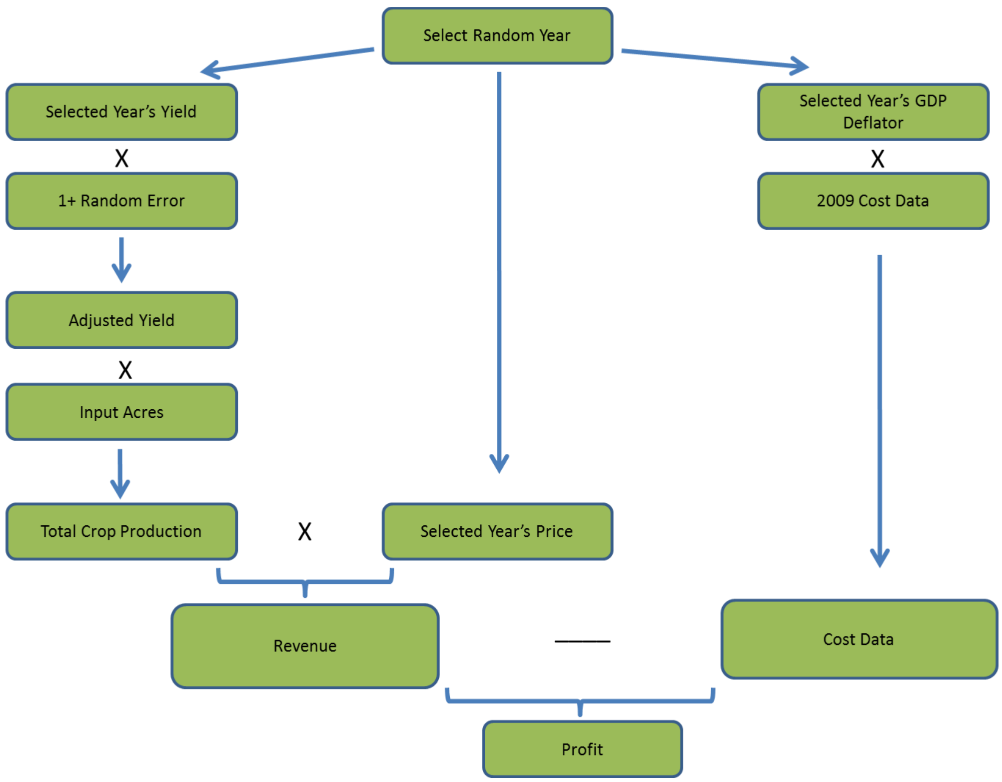

Figure 3: Single Iteration Procedure

Figure 3 illustrates the iterative process used to calculate profits for a cropping system. The iteration begins at the top of the figure when the model selects a year at random from the uniformly likely set of 1980 to 2010. When a year is selected (e.g., 1985), this becomes the base year. For the selected base year, commodity prices, yield and GDP deflator are selected. A random percent error for yield (described below) is used to calculate the adjusted yield. The number of acres in production are multiplied by the adjusted yield to calculate total yield. The product of total yield and the commodity price equals revenue. The input costs from 2009 are adjusted using the GDP ratio. The difference between the revenue and the costs quantifies the potential profit obtained from producing a particular crop. Individual crop profits are summed to generate the cropping system profit. The calculations in an iteration includes the following steps:

(1) Select random Year between 1980 and 2010
(2) Select a Yield of a particular crop from a selected random Year
(3) Select a random % error for yield (expressed in decimal form)
(4) Calculate Adjusted Yield = Yield * [(% error)/100 + 1]
(5) Input number of Acres in production of particular crop
(6) Select a Price of a particular crop from a selected random Year
(7) Calculate Revenue = Price * Adj.Yield * Acres
(8) Select a GDP deflator from a selected random Year
(9) Calculate Cost/Acre= GDP deflator * 2009 Costs
(10) Total Operating Cost= Cost/Acre * Acre
(11) Calculate Profit = Revenue - (Total Operating Costs)
(12) Calculate Total Profit = Sum of all cropping profits

Historical Bootstrapping and Crop Yields

In step (3) listed above, a percent error is randomly selected to be added to a base yield. This is done so as to not draw from the same yield frequency. This is important because adding the mean percent error to a base yield allows the model to proxy the potential variation in yields that have been demonstrated historically giving more robust results. More specifically, a de-trended error term is obtained by regressing yields on years (Pritchett, et al., 2004).The error term captures that which is not explained in the regression. This may include environmental factors that vary from year to year and impact yield. A percent error is used rather than a simple error so that it may be applied to any year's historical yield preserving the relative production risk..

Without the random error term the sample would be drawn from the historical distribution of yields, thus, the result would be the same distribution as that of the historical data. The information resulting from such distribution would be limited to describing the past. The addition of a random percent error term allows for variability and thus reflects variability yields. The regression used in the first step for obtaining the percent error for irrigated corn is shown in the equation 8 below:

(8) $$\textbf{\textit{Irrigated Corn Yield}} = B_0 + B_1\, Year + error$$

Using the data and the statistical software package STATA, the following results are obtained:

(9)	***Weld County:***	***Irrigated Corn Yield =***	***- 3184.499 + (1.673 * Year)***	
		Standard Error	***586.5779***	***1.6729***
		R-Squared	***0.5433***	

The estimated irrigated corn yield is calculated using the equation for all years from 1980-2010. Difference between the estimated and actual yield produces estimated error term:

(10) $$\boldsymbol{Estimated\ Irrigated\ Corn\ Yield_i - Irrigated\ Corn\ Yield_i = Estimated\ Error_i}$$

The quotient of the estimated error and the estimated yield is the percent error. The collection of percent errors is the frequency to be used stochastically when obtaining adjusted yield. These percent errors represent potential production risks and are invariant to the level of the yield. Equation 10 describes how the percent error is calculated for the i^{th} crop:

(11) $$\frac{\boldsymbol{Estimated\ Error_i}}{\boldsymbol{Estimated\ Yield_i}} = \%\ \boldsymbol{Error_i}$$

The percent error may be added to the base year yield as in equation (12)

(12) $$\boldsymbol{Adjusted\ Yield = Yield} * (\mathbf{1} + \%\ \boldsymbol{error\ in\ decimal\ form})$$

Consumptive Use Calculations

According to Colorado water law, any purchasing or transferring of water to an alternative use must be done in a way that ensures historical return flows in volume and timing as to not injure the other users (*The City of Colorado Springs v. Yust*, 126 Colo. 289, 249 P.2d 151 (1951); *Green v. Chaffe Ditch Co.*, 150 Colo. 91, 371 P.2d 775 (1962)) Thus, the only portion of the water that may be transferred is the part used by the crop, also referred to as water consumptively used.

In order to arrive at the amount of consumptive use (CU) conserved with an alternative cropping system to that of the baseline, crop specific consumptive water use data is needed. This calculation begins with overall crop water requirements (Schneekloth, Andales, 2009) specific to the South Platte River Basin. Next, the effective precipitation is subtracted from the water requirement to obtain the amount of consumptive use, or net water requirement, needed for the crop. Given a particular number of acres of a specific crop, the net water requirement at the root is calculated using the Andales and Schneekloth data. The product of the crop consumptive use and acreage yields the total net water requirement for a given crop. This value is used as a baseline water amount. The amount of water conserved the difference between the baseline's consumptive use and the alternative system's consumptive use.

To estimate profits, costs must be subtracted from the revenues. The costs are obtained using 2009 farm enterprise budgets that are available on the CSU Extension page of Agriculture and Business Management. The enterprise budgets are then adjusted to represent the accounting costs that producers face. Thus items such as crop consultant, crop insurance, custom application, sprinkler lease, and interest expenses are removed from the calculations under the assumption that the producer compensates for these cost through personal labor. This leads to cash or accounting profit, rather than opportunity cost or economic, calculation of profit. Since only the accounting profit is being considered in this case, opportunity cost for producer labor is not included in the model. Therefore, although computation of the accounting profit rather than economic profit may be a limitation, in this particular case, it is a more accurate reflection of the profits that producers face. In addition, the 2009 costs are deflated using the Gross Domestic Product (GDP) deflator value associated with the randomly selected year.

Given the price and adjusted yield data along with the deflated operating costs, profits are estimated. The multiple iteration of this simulation produces a distribution of yield, prices and profits for variety of cropping systems that a producer might adopt when seeking to conserve consumptive water use. In addition, the opportunity cost of choosing one cropping system over another (as shown in equation 7) is collected in each iteration. These frequencies may then be compared using various risk criteria.

CHAPTER 4: RESULTS AND ANALYSIS

All computations and results described within the text have been conducted for the representative farms of Weld and Logan counties using the *Baseline 1* and *Baseline 2* cropping systems. This chapter reports and contrasts the results of the model simulation. Analysis focuses on the results from Weld County, *Baseline 1*. The other cases are not discussed in great detail, although, they may be referenced from time to time as curious outcomes occur. Omitted results, organized in charts, graphs and tables, are available for reference in Appendix A of this thesis.

Results from Initial Simulation Procedure

Simulation results are obtained via an iterative procedure represented by Figure 3. A single year between 1980 and 2010 is stochastically selected from the data series. Yield and price corresponding to the selected year are drawn. The yield is adjusted using a stochastically selected percent error obtained via de-trending of yield or year. The cost data is adjusted for the selected year using the GDP deflator centered on 2009. All the information is used to arrive at revenue and corresponding cost and ultimately profit. The iteration of this procedure yields the set of results used for the analysis in this thesis.

All simulation results have been collected, but some outliers have been omitted from the analysis. As an example approximately 4% of the simulation results from year 2010 have shown to be highly profitable outliers driven by exceptionally high prices of wheat, corn and alfalfa in that year. These observations are omitted from the simulation results. To include the data for 2010 would be to say that every 1 out of 30 years prices and yields are both extremely high. This is inconsistent with historical data, thus would sway the results and inaccurately represent the situation producers would face most of the time, by understating risk associated with yield and price variation.

In addition, approximately 20% of the simulation results between years 1998 and 2003 resulted in negative profits. Emergency disaster payments were made to farmers in 1998, 1999, and 2000 when direct payments were increased. These direct payments are made based on historical, rather than current, market prices and yields. The data for these payments was not readily available, so profits in these years are understated. As a result, profits in the years 1998-2003, for which there is too little data, are omitted from analysis.

For reference, Figures 4 and 5 provide a graphical representation of the data at the Weld County level, *Baseline 1* cropping system. Note that once the outliers of 1998-2003 and 2010 are removed, a more consistent data set exists. In addition, an upward trend in the profits from 2004 to 2010 is observed. These values appear to exist due to an increase in the prices and yields of irrigated crops . This information is kept within the data set as it is plausible in the future for prices and yields to be as high. Keeping these values for the simulation process helps reflect variability of profits from year to year. After adjusting the data, 388 observations remain from 500 originally simulated iterations.

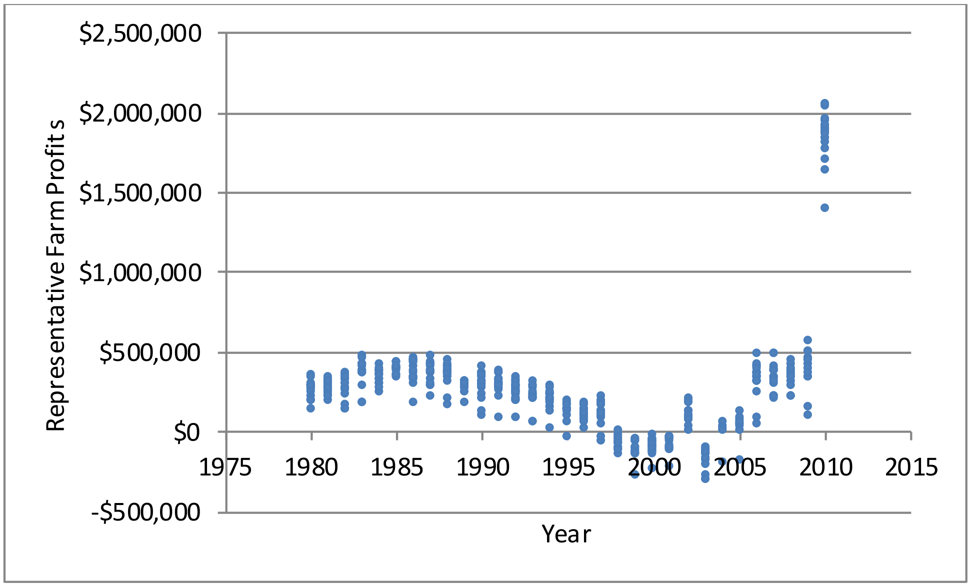

Figure 4: Simulation Results of Profits vs. Years for the *Baseline 1* in Weld County

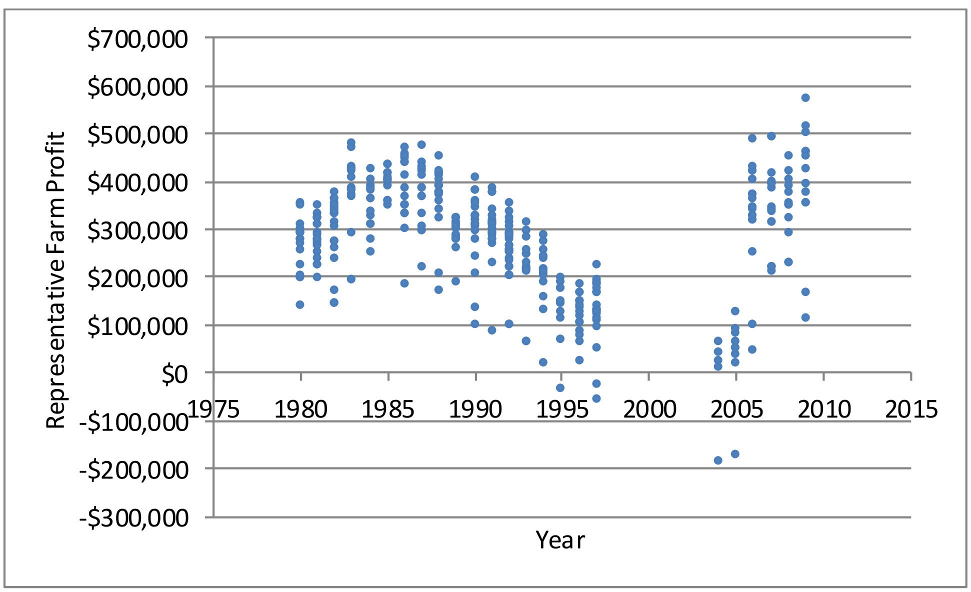

Figure 5: Adjusted Simulation Results of Profits vs. Years for the *Baseline 1* in Weld County (Note that the vertical axis is scaled differently compared to Figure 4)

Descriptive Statistics

The purpose of his section is to compare the alternative cropping systems to the baseline cropping system. Particular outliers are noted and omitted. The analysis then continues as the production systems are compared to the baseline based on summary statistics.

To ensure that 500 iterations would be sufficient and representative amount of data for analysis, a simulation of 1000 iterations is conducted. The summary statistics between the 500 and 1000 iterations are compared and it's established that statistical outcomes are the same in both cases. This conclusion is reached after examining the summary statistics such as mean, median, standard deviation, minimum and maximum numbers. Tables 5 and 6 display the summary statistics for profits. These figures include statistics for the complete simulation set of 500 iterations as well as the adjusted data of 388 iterations.

When evaluating distributions, the summary statistics provide an initial examination of differences. Examining mean and standard deviation values for profit is useful; however, it is also important to take a close look at the variation in the economic measures. Risk neutral measures such as coefficient of variation, first degree stochastic dominance, and comparing the foregone opportunity cost are used in the analysis.

As mentioned previously, two typical historical cropping systems are used for the baselines:

Baseline 1 Fully irrigated continuous corn

Baseline 2 2/3 irrigated corn and 1/3 irrigated alfalfa rotation.

Likely adaptions to conserve consumptive use include:

Cropping System A 2/3 irrigated corn and 1/3 fallow rotation

Cropping System B 1/3 irrigated corn, 1/3 irrigated alfalfa and 1/3 fallow rotation

Cropping System C 1/2 irrigated corn and 1/2 dry land wheat rotation

Cropping System D 1/2 irrigated corn and 1/2 irrigated wheat rotation.

It should be noted that these rotations do not include a payment for leased water so profits for the alternative cropping systems are expected to be less than the baseline. Summary statistics for all simulated data and adjusted data are displayed in Tables 5 and 6 respectively.

Table 2: Summary Statistics of Profits for a Representative Farms for Weld County *Baseline 1* using All Simulated Data

STATISTICS	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	$ 290,519	$ 193,689	$ 112,600	$ -39,029	$ 103,081
St. Dev.	$ 390,409	$ 260,285	$ 223,499	$ 310,131	$ 312,242
COV	134	134	198	-794	302
Min	$ -288,073	$ -192,058	$ -268,328	$ -452,181	$ -362,486
Max	$ 2,063,254	$ 1,375,572	$ 1,162,592	$ 1,275,567	$ 1,408,026

Table 3: Summary Statistics of Profits for a Representative Farms for Weld County *Baseline 1* using Adjusted Data

STATISTICS	*Baseline 1*	*Cropping System A*	*Cropping System B*	*Cropping System C*	*Cropping System D*
Mean	$ 285,522	$ 190,357	$ 113,172	$ -35,625	$ 116,461
St. Dev.	$ 118,254	$ 78,840	$ 83,988	$ 118,659	$ 125,568
COV	41	41	74	-333	108
Min	$ -181,317	$ -120,884	$ -111,788	$ -441,059	$ -286,183
Max	$ 578,211	$ 385,493	$ 427,664	$ 227,808	$ 443,414

Mean profits can be placed in descending order from *Baseline 1*, to *Cropping System A*, *Cropping System D*, *Cropping System B*, and lastly *Cropping System C*. Standard deviation ranked in the descending order starts with *Cropping System D*, followed by *Cropping System C*, *Baseline 1*, *Cropping System B* and *Cropping System A*. *Baseline 1* and *Cropping System A* have the lowest covariance followed by *Cropping System B*, *Cropping System C* and *Cropping System D* in an ascending order. *Cropping System A* appears to be most preferred as it has the highest mean profits, lowest standard deviation and covariance.

Most producers face production risks within their operations. According to the Agricultural Resource Management Survey (ARMS), formally known as Farm Costs and Returns Survey (FCRS), crop producers are most concerned about the yield and price risk than other risk categories (Managing Risk, ERS). Yield risk is a result of variation in weather, soil type, irrigation employed as well as the region in which production takes place. Price risk is impacted by commodity stock levels, national and international demand. Other risks, such as institutional and personal, are not attempted to be captured within this study. Instead the focus lies on the analysis of price and yield risk under a water leasing agreement is explored below.

Given risk preferences of an individual, conclusions can be drawn about which case will yield greatest utility. It is believed that in most cases, producers are risk averse and their decisions are based on two characteristics: meeting the minimum cash flow to cover debt obligations minimizing the probability for the lowest profits. Thus, for a farm manager to maximize their utility, a cropping system with least amount of variability and highest payoffs would be most preferred. Likewise, a risk averse producer would be willing to give up a portion of profit for the reduced variability in the income. Identifying these characteristics about each of the alternative cropping systems allows for exposure of variability implications in each case. Although most of the analysis measures assume risk neutrality, the information revealed allows individual producers to choose most suitable option based on their personal risk preferences.

Mean or standard deviation measures are useful, but may be misleading when assessing each system. For example, a case of higher mean returns may very well involve larger variation, and thus greater degree of risk. Furthermore, distributions can be skewed and the minimum loss or the frequency of losses and/or maximum gain, may be an important component of a farmer's decision process. Thus mean and standard deviation alone are not sufficient measure to describe risk within different cropping systems. Looking at the distribution of profits leads to more informed analysis. Descriptive strategies include displaying cumulative distribution frequencies, probability density frequencies, and coefficient of variation is employed to evaluate and compare the risk across cropping systems. The following paragraphs describe and compare risk and profit variation associated with each cropping system.

Comparing the entire profit frequencies between cropping systems is telling. In Table 7 the results are analyzed by looking at the percentage of outcomes that are below and above the mean profit of *Baseline 1* for each of the different cropping systems.

Table 4: Percent of Iterations of Profits Given Various Parameters and No-Compensation for Water Removed from Production in Weld County, in relation to *Baseline 1* Mean Profits

Total Iteration Number = 388, Weld County (Mean Profit = 285,522)					
% ITERATIONS IN WHICH…	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Profit < Baseline1 Mean Profit	41.75%	90.21%	93.30%	97.68%	91.24%
Profit < 10 % below Baseline1 Mean Profit	34.02%	78.35%	92.53%	97.68%	86.34%
Profit < 20 % below Baseline1 Mean Profit	28.61%	63.14%	89.69%	97.68%	79.90%
Profit > Baseline1 Mean Profit	55.93%	7.47%	4.38%	0.00%	6.44%
Profit > 10 % above Baseline1 Mean Profit	44.85%	2.58%	3.35%	0.00%	4.12%
Profit > 20 % above Baseline1 Mean Profit	34.54%	0.52%	1.80%	0.00%	1.29%
Profit < 0	1.29%	1.29%	5.93%	57.22%	16.49%

Baseline 1 mean profit for Weld County is $285,522 where 100% of the available acres are devoted to irrigated corn. With *Baseline 1* as an original cropping mix choice, the producer faces 41.75% of outcomes where the profits fall below the *Baseline 1* average value, suggesting the frequency is skewed, while 55.93 % of outcomes profits are above the *Baseline 1* average value. *Cropping System A* has the least percentage of

outcomes that fall below the *Baseline 1* average, 90.21%, when compared to the other cropping alternatives. *Cropping System C*, however, has the greatest percentage of outcomes that fall below the mean *Baseline 1* profit when compared to the other cropping alternative, 97.68%. *Cropping System A* also has the greatest percentage of iterations of profits that are above the *Baseline 1* average profit, 7.47%, compared to other Cropping Systems. On the other hand, *Cropping System C* has 0 % cases where profits exceed the Baseline average. Under the *Baseline 1* Cropping System, profits fall below zero 1.29% of the time. This is also the case for the *Cropping System A* profits. *Cropping System C*, however, reaches negative profits 57.22% of the time.

With this information it can be concluded that *Cropping System A* generally has outcomes that are most similar to *Baseline 1* case relative to the other cropping systems. *Cropping System A* contains the least number of outcomes of negative profits and the smallest frequency of profits below the Baseline 1 mean as compared to other cropping systems. In contrast, *Cropping System C* is the "worst" system from a producer's perspective. Thus, although *Cropping System C* might be a typical cropping system adaptation for the South Platte River Basin, it shows to be the riskiest with highest probability of lowest returns. A producer who is risk averse would find *Cropping System C* least preferred if profit is the major factor influencing producer's decision.

Slightly different conclusions are drawn from looking at the frequencies of alternative cropping systems' profits in relation to *Baseline 2* average profit. The table below illustrates the frequencies.

Table 5: Percent of Iterations of Profits Given Various Parameters and No-Compensation for Water Removed from Production in Weld County, in Relation to *Baseline 2* Mean Profits

Weld County (Mean Profit = 191,520)	***Baseline 2***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Profit < Baseline2 Mean Profit	45.62%	47.42%	85.05%	96.65%	67.78%
Profit < 10 % below Baseline2 Mean Profit	37.89%	37.89%	80.93%	95.88%	63.92%
Profit < 20 % below Baseline2 Mean Profit	30.41%	34.02%	77.06%	94.85%	58.25%
Profit > Baseline2 Mean Profit	52.06%	50.26%	12.63%	1.03%	29.90%
Profit > 10 % above Baseline2 Mean Profit	43.30%	39.69%	10.31%	0.00%	23.45%
Profit > 20 % above Baseline2 Mean Profit	35.31%	30.93%	7.99%	0.00%	19.07%
Profit < 0	8.25%	1.80%	10.31%	57.73%	21.13%

Recall that *Baseline 2* is a 2/3 irrigated corn and 1/3 irrigated alfalfa crop rotation. *Baseline 2* mean profit for Weld County is $191,520. In the case of *Baseline 2* profits fall below the mean 45.62% of the time. *Cropping System A* follows closely with profits falling below *Baseline 2* average 47.42 % of the time. More interesting is that *Cropping System A* results in negative profits 1.80% of the time, while *Baseline 2* has 8.25% chance of profits falling below zero. Thus, switching operations from *Baseline 2* to *Cropping System A*, the frequencies above suggest that variability in profit is reduced as a result. This makes sense since *Baseline 2* consists of 2/3 irrigated corn and 1/3 alfalfa and *Cropping System A* consists of 2/3 irrigated corn and 1/3 fallow. Removing irrigated alfalfa from the production operation results in fewer iterations with negative profits.. Profit risk is reduced by not producing alfalfa and as result, the variation in profits decreases.

It is important to note that although profit risk is eliminated on a portion of the land that is fallowed, overall household income derived from the farming operation is decreased. This reduces cash flow for living expenses and debt repayment. .

Lastly, *Cropping System C* remains the case of most profits below the baseline average, least profits above the average and most number of negative profits. *Cropping System C* exhibits greatest amount of risk and lowest returns. Thus, given a risk-averse preference of a producer it is the least favorable cropping system.

Calculating the Foregone Opportunity for Profit between the Baselines and Other Cropping Systems

Results may also be categorized and evaluated on a per affected acre basis. If alternative cropping system profits are subtracted from the baseline, then the difference can be interpreted as an opportunity cost for choosing an alternative cropping system hat conserves consumptive use. The difference (opportunity cost) is calculated within each iteration, and then divided by the affected acreage: fallow, dry-land or alternative crop acres. Refer to Figure 6 for the visualization of the computation procedure.

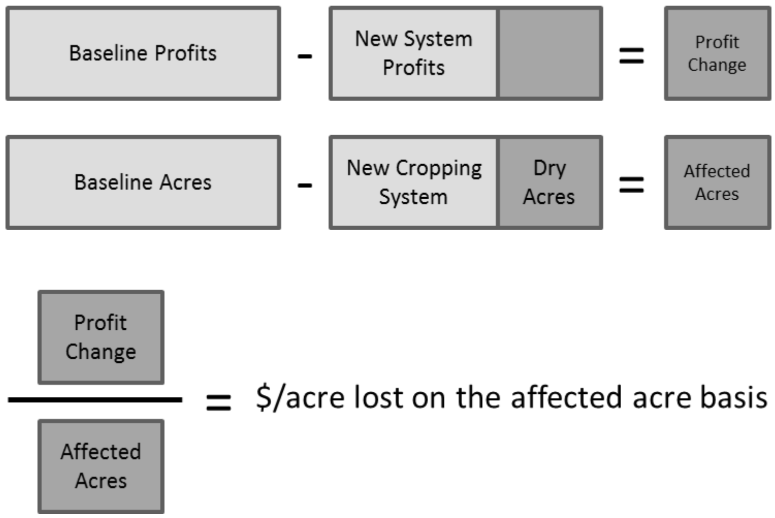

Figure 6: Computational Procedure to Arrive at $/Acre Lost with an Alternative Cropping System

Table 9 below shows the summary statistics of the opportunity cost per affected acre. This is an opportunity cost because the producer foregoes profit by no longer irrigating production on that portion of the land. One interpretation of this value is an ex poste compensation that might be paid to a producer for signing a lease.

Examining Table 9, *Cropping System B* has the lowest mean foregone opportunity cost of $129.00 per acre while *Cropping System A* has the lowest standard deviation of foregone opportunities of $59.00 per acre. This means that, on average, the Baseline 1 outperformed *Cropping System B* by $129 per acre, *Cropping System A* has the least variation in profit around its mean opportunity cost of $143. Choosing *Cropping System C,* results in $321.00 of opportunity cost per affected acre, on average, and the largest standard deviation from the mean of $94.00. Thus, the average amount required for compensation will be much greater in *Cropping System A* or *Cropping System B* than in *Cropping System C*.

Table 6: Summary Statistics of Potentially Forgone Profits Loss $/Affected Acre for a Representative Farm for Weld County *Baseline 1* Adjusted Data

	Potentially Forgone Profits , $/Acre			
STATISTICS	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	$ 143	$ 129	$ 321	$ 169
St. Dev.	$ 59	$ 72	$ 94	$ 88
COV	41	56	29	52
Min	$ -91	$ -94	$ 131	$ -76
Max	$ 289	$ 301	$ 622	$ 494

Figures 7 through 10 are histograms displaying opportunity cost frequencies the Weld County representative farm. . Looking at the following graphs, variation in opportunity cost and the shape of the distributions is evident. *Cropping System A* provides the least variation and the lowest average opportunity cost for the per affected acre compensation. At the same time, *Cropping System B* has the widest range of values, while *Cropping System C* has the highest average opportunity cost for the per acre base. Thus, *Cropping System A* has the least foregone opportunity cost per acre variability of the chosen crop revenues when compared to the *Baseline 1.* It is important to note that not only the down side risk variability of earning negative profits is reduce d, but so is the upside of achieving higher profits. Given that the producer chooses to switch from *Baseline 1* to *Cropping System A*, in order to lease water, the distribution suggests that they would need to be compensated $143.00 per affected acre on average and $289.00 maximum per affected acre.

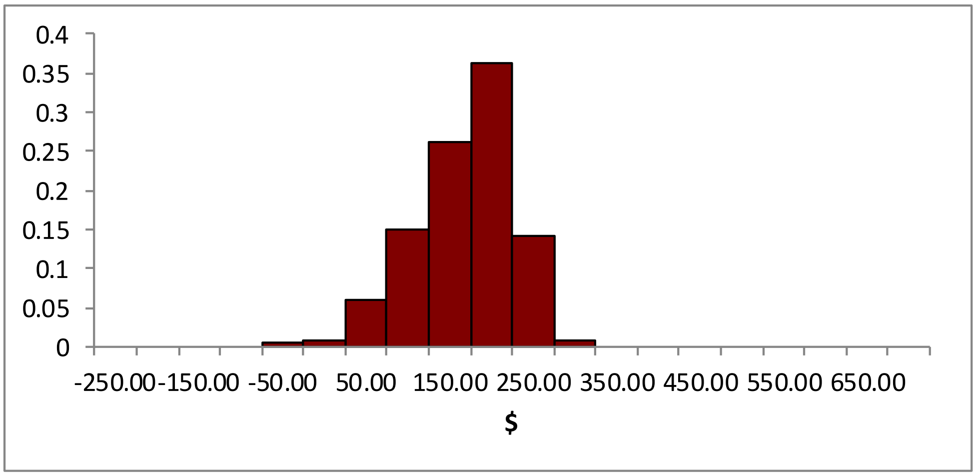

Figure 7: ***Cropping System A*** **$/ Dry Acre Potentially Forgone Profits in Weld County, Baseline1**

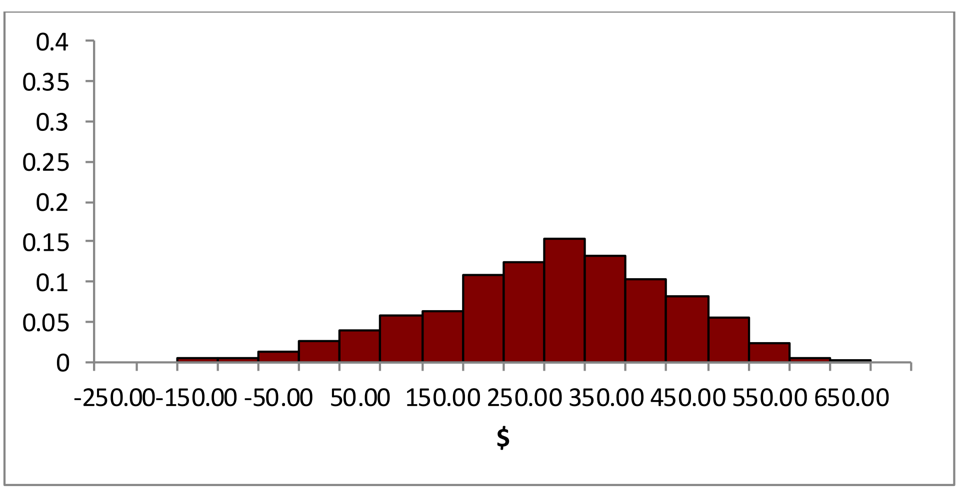

Figure 8: ***Cropping System B*** **$/ Dry Acre Potentially Forgone Profits in Weld County, Baseline1**

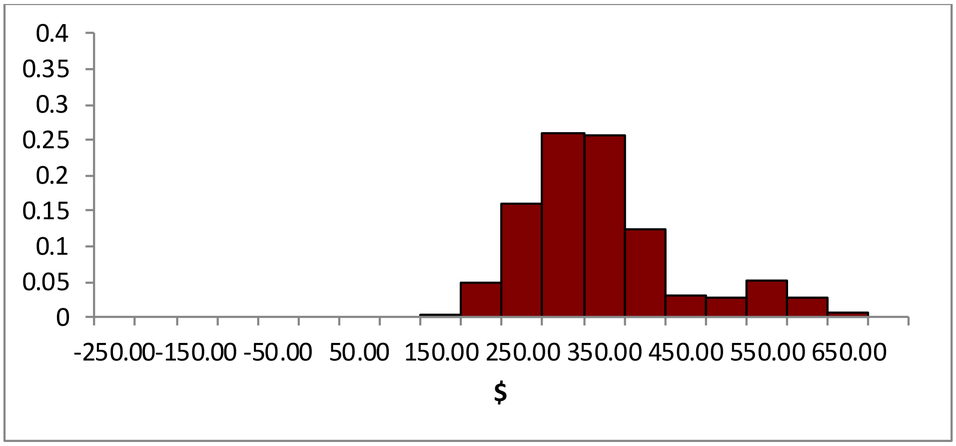

Figure 9: ***Cropping System C*** **$/ Dry Acre Potentially Forgone Profits in Weld County, Baseline1**

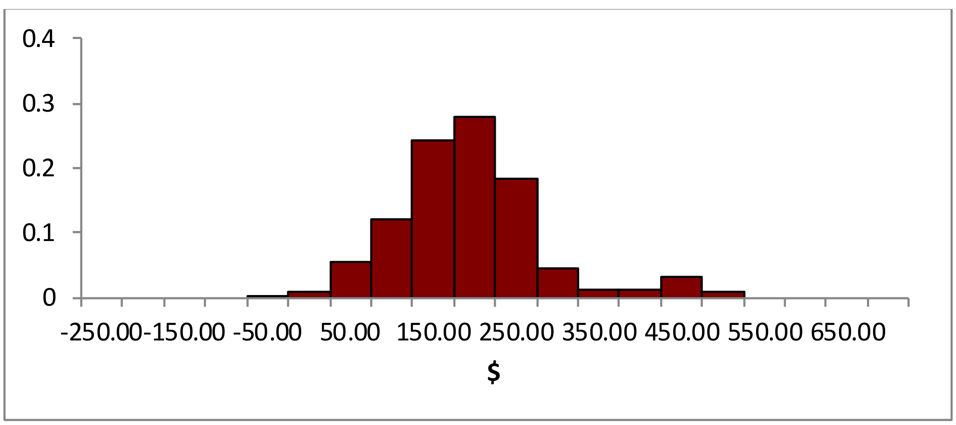

Figure 10: ***Cropping System D*** **$/ Dry Acre Potentially Forgone Profits in Weld County, Baseline1**

Yet another way to approach the question of foregone opportunity cost is to look at the difference between Baseline and various cropping system profits in terms of consumptive use (CU) of water. Note that CU is obtained as a net water amount after precipitation, and crop water requirements are assumed to be met fully. The conserved

CU is measured against this full amount; the actual amount of conserved water can only be determined after harvest. In short, the conserved CU that fulfills crop water requirements on average may be different than actual conservation. Our approach (assuming full crop water requirements are met and netting out precipitation) is a least cost approach at the current time, and one most likely to be adopted when leases are signed.

Opportunity cost to water conservation is calculated on CU basis. This is done by computing the differences between the Baseline profits and Alternative Cropping System profits. The difference is then divided by the number of consumptive acre feet of water removed from production (Figure 11).

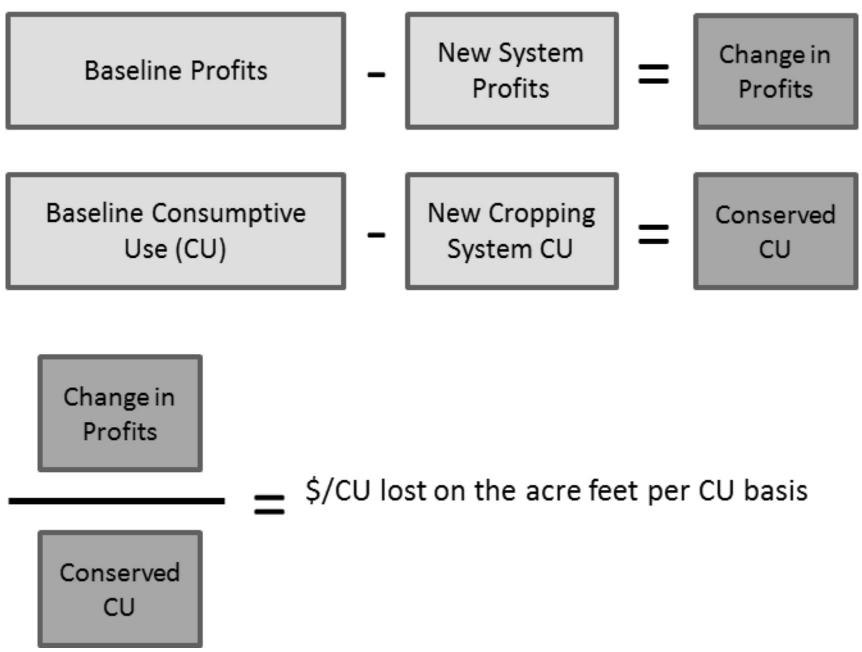

Figure 11: Computational Procedure to Arrive at $/CU Lost with an Alternative Cropping System

Table 10 below shows the summary statistics of the dollar value per acre foot of CU saved. Simply put, the lower the value per unit of CU savings, the smaller the foregone opportunity when switching from the baseline to an alternative cropping system. In this evaluation, *Cropping System A* has the lowest mean of $119.00 per acre foot CU and the lowest standard deviation of $49.00 per acre foot CU. *Cropping System B* in this case has the highest mean per acre foot CU of $605.00 as well as the highest standard deviation of $339.00. These results suggest that given a producer who selects *Cropping System A*, the dollar value for compensation of an acre foot of water is much lower on average than if the producer chooses to select *Cropping System B*.

Table 7: Summary Statistics of Potentially Forgone Profits, $/CU for a Representative Farm for Weld County *Baseline 1* Adjusted Data

	Potentially Forgone Profits, $/CU			
STATISTICS	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	$ 119	$ 605	$ 269	$ 384
St. Dev.	$ 49	$ 339	$ 79	$ 200
COV	41	56	29	52
Min	$ -76	$ -438	$ 110	$ -174
Max	$ 242	$ 1,411	$ 521	$ 1,122

The following histograms represent a distribution of dollar values per acre foot CU between the *Baseline 1* and the all the alternative cropping systems.

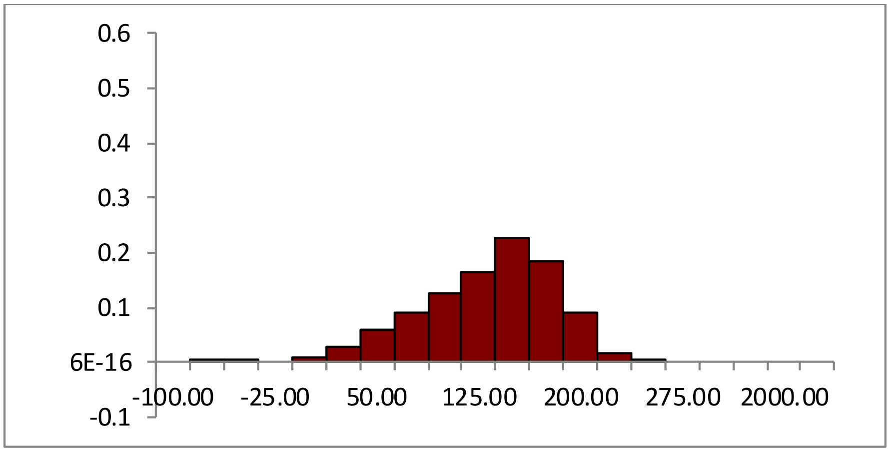

Figure 12: ***Cropping System A*** **$/ CU Potentially Forgone Profits in Weld County, Baseline1**

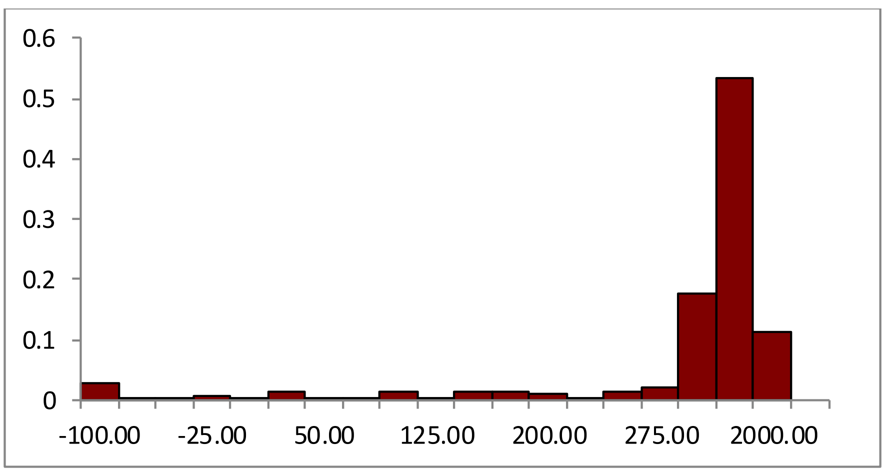

Figure 13: ***Cropping System B*** **$/CU Potentially Forgone Profits in Weld County, Baseline1**

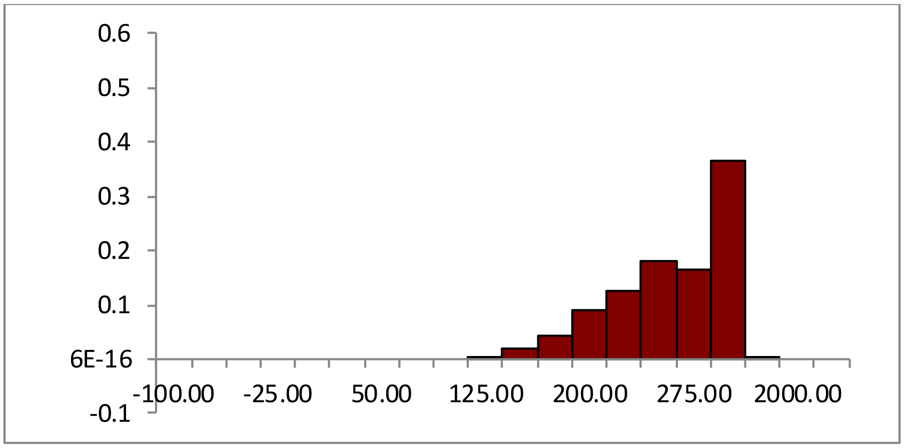

Figure 14: ***Cropping System C*** **$/ CU Potentially Forgone Profits in Weld County, Baseline1**

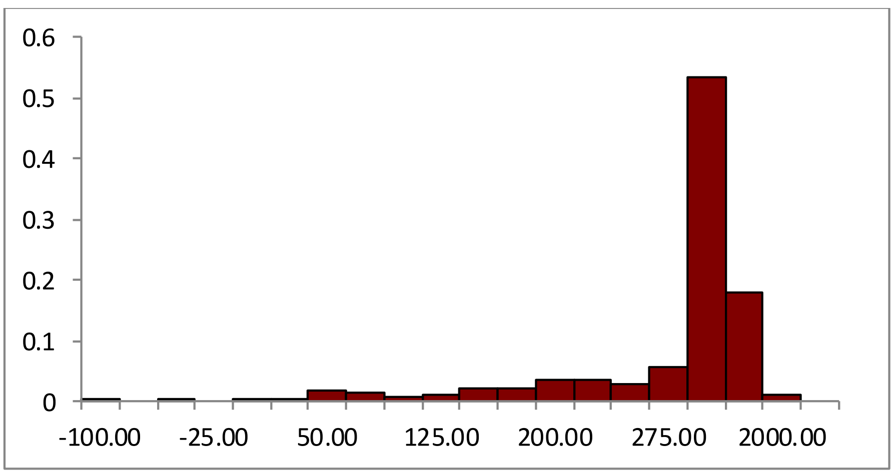

Figure 15: ***Cropping System D*** **$/ CU Potentially Forgone Profits in Weld County, Baseline1**

Each of the distributions is skewed to the have long tails to the left, which suggests that in rare occurrences the th4e profits per CU of conserved water are greater than those of the baseline cropping system. *Cropping System A* presents the least amount of variation in the dollar value per CU of AF with a range between -$760 and $242, while *Cropping System B* presents the greatest amount of variation with the range between -$438 and $1,411. This means that when changing from *Baseline 1* to *Cropping System A*, the producer could potentially face the described distribution for the value of water removed from production. The distribution represents the set of values that producer would need to be compensated (or in some instances must pay) in order to replicate *Baseline 1* profit outcomes. That implies that when choosing *Cropping System A*, a producer needs the least amount of monetary compensation for the water not to be used in irrigated production. Selecting *Cropping System B*, however, would require a producer to be compensated much larger amounts for conserved water, given that there is much greater variability in order to reach the *Baseline 1* distribution of profits previously faced. With this information, it can be concluded that when choosing *Cropping System A*, the producer faces the least amount of risk due to variation in profit.

Table 8: Potentially Forgone Profits Comparison $/Acre vs. $/af CU

	Cropping System A		***Cropping System B***		***Cropping System C***		***Cropping System D***	
	Acres	CU (AF)	Acres	CU (AF)	Acres	CU (AF)	Acres	CU (AF)
Units	666.66	797	666.66	285	1000	1195	1000	440
STATISTICS	$/Acre	$/CU	$/Acre	$/CU	$/Acre	$/CU	$/Acre	$/CU
Mean	$ 143	$ 119	$ 129	$ 605	$ 321	$ 269	$ 169	$ 384
St. Dev.	$ 59	$ 49	$ 72	$ 339	$ 94	$ 79	$ 88	$ 200
COV	41	41	56	56	29	29	52	52
Min	$ -91	$ -76	$ -94	$ -438	$ 131	$ 110	$ -76	$ -174
Max	$ 289	$ 242	$ 301	$ 1,411	$ 622	$ 521	$ 494	$ 1,122

Cummulative Distribution Frequencies (CDF) of of cropping system profits is another means of comparing risk and return tradeoffs with baseline cropping. . Figure 16 displays the CDFs for Weld County *Baseline 1* and the alternative cropping systems.

Cummulative Distribution Functions and Stochastic Dominance

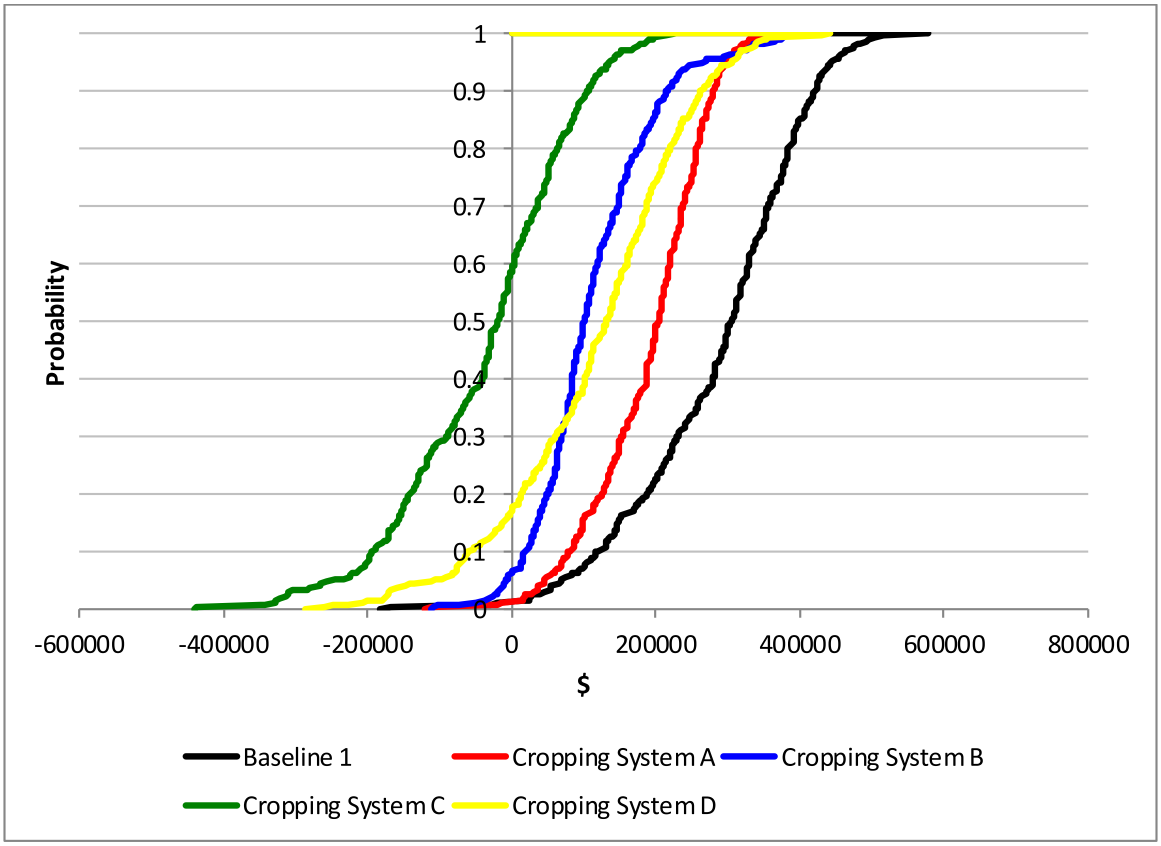

Figure 16: Cumulative Distribution Frequencies for *Baseline 1* and the Four Alternative Cropping Systems for Weld County

Table 9: Important Values from the CDF *Baseline 1* for Weld County

WELD	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
50%	$305,943	$203,972	$101,413	-$18,727	$130,652
Profit < $0	1.00%	1.00%	5.80%	58.47%	16.67%
Profit > $250,000	66%	24%	6%	0%	13%

The left hand tail of the CDF's in Figure 16 are of particular interest to farmers – these tails indicate the cumulative likelihood of negative profits or failure to meet some level of critical cash flow. An interesting observation is that *Cropping System A* follows the *Baseline 1* closest, especially along the lower tail of the distributions. Although the disparity increases in the higher ends of the two distributions, there is the least amount of risk in the lower end of profits when switching to *Cropping System A* from *Baseline 1*. Interestingly, *Cropping System C* has the highest disparity between the *Baseline Cropping System* along with the greatest probability of negative profits. Comparing *Baseline 1* and *Cropping System A* shows that *Cropping System A* has less variation than the *Baseline 1.* This means that there exists lower risk of obtaining negative profits. *Cropping System C* has 57.94% chance, *System D* haS 15.87% chance followed by *System B* that has about 5.29% probablity of obtaining negative profits. *Baseline 1* and *Cropping System A* both have 1.1% chance of profits falling below zero. However, the reduced variation on the lower tail end of the distribution also reduces the possibility of obtaining highest profits at the high tail end of the distribution when compared to *Baseline 1* profits. It can be hypothesized that provided a compensation payment for water removed from production, *Cropping System A* would obtain higher profits than those previously due to the payment but would still retain its lower risk level. Depending on the value of the payment, this may lead *Cropping System A* to become a most preferred option given that a producer is risk averse and thus prefers more certainty in the profits received.

To test this Figure 17 shows the CDFs for the Cropping Systems given a compensation of $28.00 for an acre foot CU removed from production for leasing. In this case, only a slight change is observed with regards to the *Cropping System A* in the lower tail end on the distribution. It appears that the risk of obtaining low or negative profits has decreased as a result of the $28.00 compenstion payment for water removed from production.

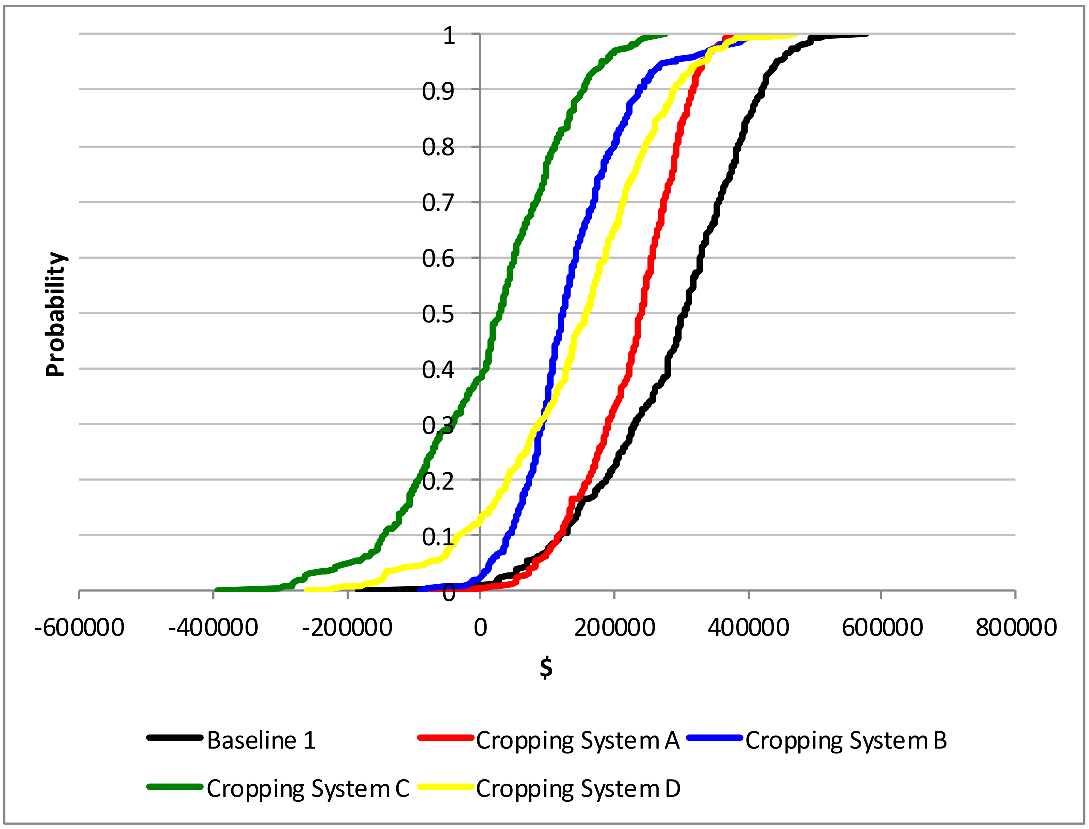

Figure 17: Cumulative Distribution Frequencies for *Baseline 1* and the Four Alternative Cropping Systems with a Compensation Payment of $28 for Weld County

Table 10: Important Values to Note for *Baseline 1* Case and Alternative Cropping Systems with $28 Payment

Baseline 1 WELD	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
50%	$305,943	$240,665	$123,778	$29,121	$157,360
Profit < $0	1.00%	0.20%	2.00%	38.10%	12.70%
Profit > $250,000	66%	44%	8%	0%	18%

Table 11: Change in Mean Profits with $28.00 Payment *Baseline 1* Weld County

Baseline 1 WELD	Mean Total Profit ($)			
	Cropping System A	***Cropping System B***	***Cropping System C***	***Cropping System D***
w/out payment	$ 166,997	$ 100,244	$ -45,889	$ 44,593
w/ $ 28.00 payment	$ 227,046	$ 135,533	$ 12,219	$ 143,165

Figure 18 displays CDFs for Weld County *Baseline 2* and the corresponding alternative cropping systems. Note that *Cropping System A* has the least amount of risk of obtaining a negative profit as compared to all cropping cropping systems, including the *Baseline 2*. *Cropping System C* has a 59.42% chance, *System D* has 20.95% chance followed by *System B* that has 9.81% probablity of obtaining negative profits. *Cropping System A* has a 1.59% chance, while *Baseline 2* has a 9.55% chance of obtaining negative profits. The two systems diverge toward the higher end of the two distributions where *Baseline 2* captures the greater probability of higher profits than *Cropping System A*. However, given that *Cropping System A* has the least amount of variation, it also has the least amount of risk. *Cropping Cropping System C* remains least favourable, as it has the greatest probability of negative profits for the majority of the distribution as compared to other cropping systems.

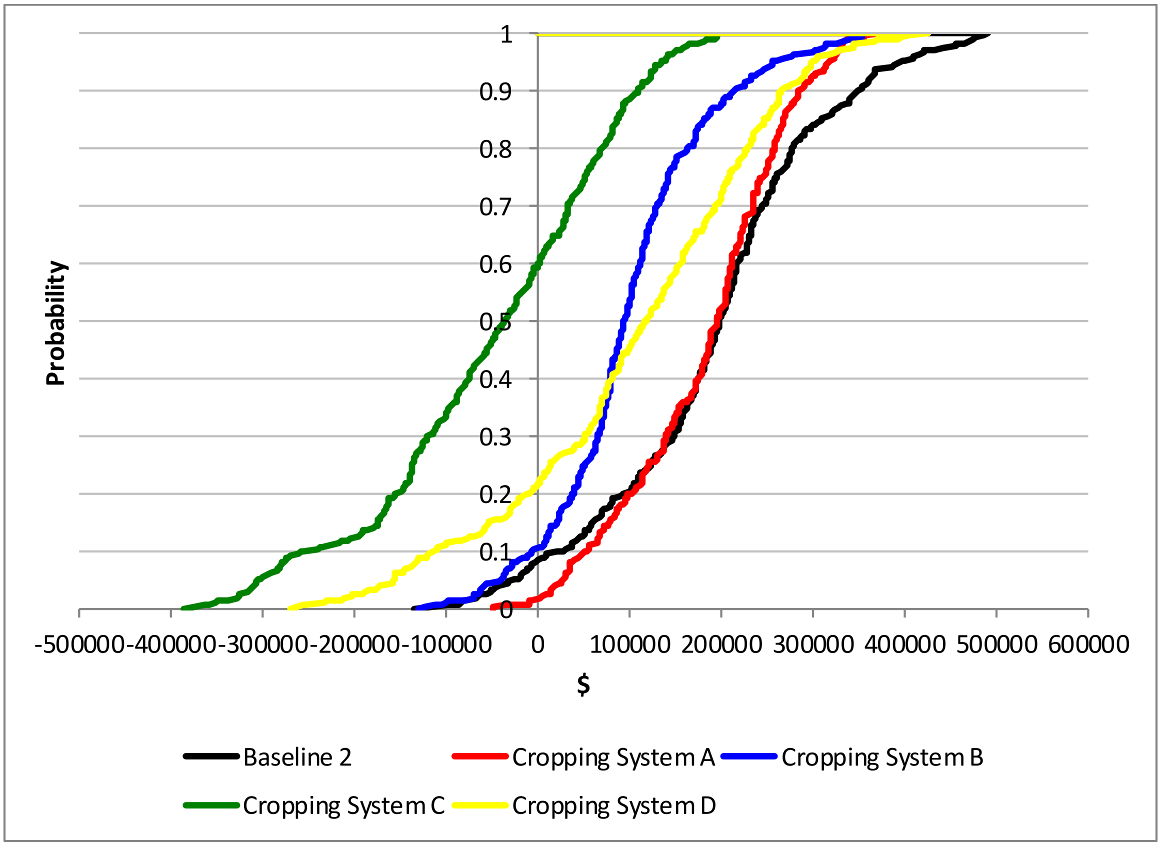

Figure 18: Cumulative Distribution Functions for *Baseline 2* and the four Alternative Cropping Systems for Weld County

Table 12: Important Values to Note from the CDF *Baseline 2* for Weld County

Baseline 2 WELD	***Baseline 2***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
50%	$197,582	$196,615	$93,869	-$36,106	$117,920
Profit < $0	8.00%	1.60%	10.35%	59.15%	21.49%
Profit > $250,000	29%	23%	6%	0%	15%

CDF's generated with the incorporation of the compensation of $28.00 per acre foot of CU removed from production for leasing for *Baseline 2* in Weld County are displayed in Figure 19. In this case different conclusions are drawn from the case of compensation vs non-compensation for water leased. *Cropping System A* has even lower risk of obtaining negative profits than before as compared to *Baseline 2* and all other cropping Cropping Systems. In fact *Cropping System A* provides higher probability of greater profits through most of the distribution when compared to all other cases aside from the highest profits, where the *Baseline 2* dominates.

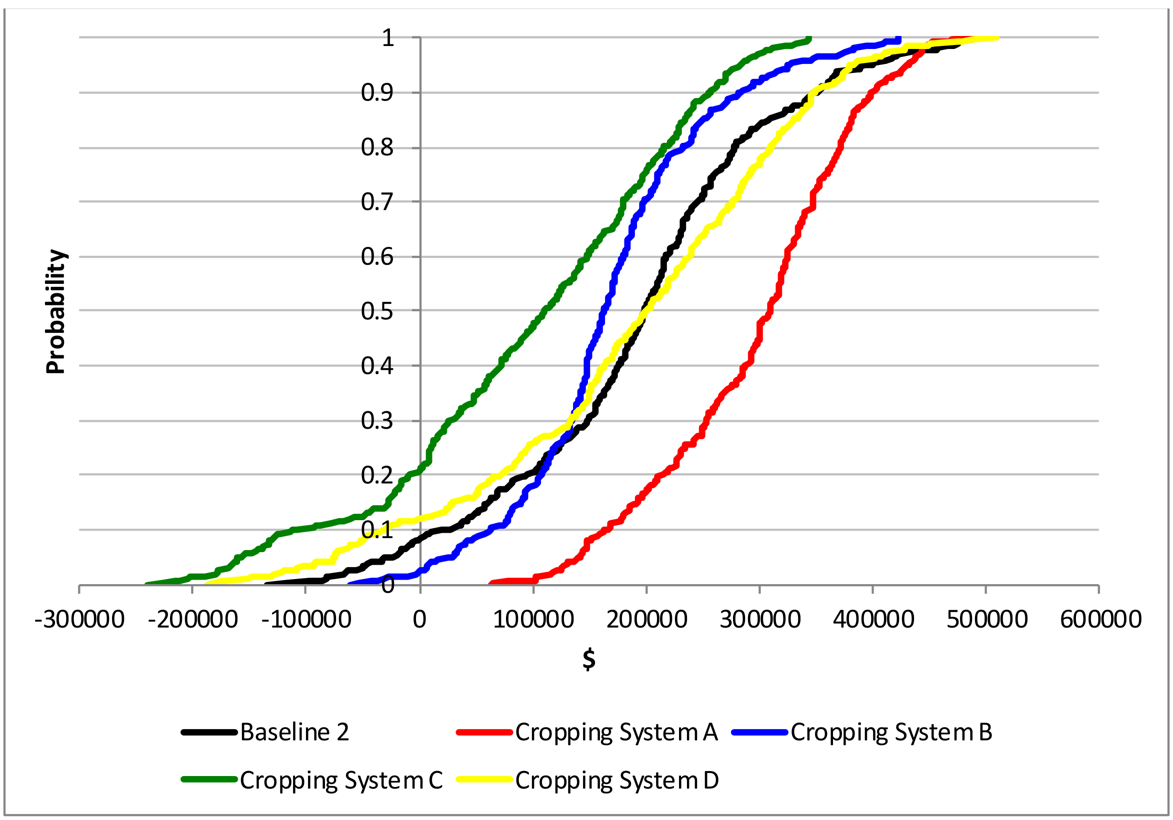

Figure 19: Cumulative Distribution Functions for *Baseline 2* and the Four Alternative Cropping Systems with Compensation Payment of $28.00 for Weld County

Table 13: Important Values to Note for Baseline 2 Case and Alternative Cropping Systems with $28 Payment

WELD (w/ $28)	*Baseline 2*	*Cropping System A*	*Cropping System B*	*Cropping System C*	*Cropping System D*
50%	$197,582	$309,313	$162,561	$110,855	$199,952
Profit < $0	8.00%	0.00%	1.85%	20.95%	11.94%
Profit > $250,000	29%	72%	15%	11%	34%

Table 14: Change in Mean Profits with $28.00 Payment Baseline 2 Weld County

Baseline 2 WELD	Mean Total Profit ($)			
	Cropping System A	*Cropping System B*	*Cropping System C*	*Cropping System D*
w/out payment	$182,223	$100,305	-$49,799	$104,272
w/ $ 28.00 payment	$218,911	$122,666	-$1,955	$130,976

Similar conclusions are made about the CDFs for *Baseline 1* and *Baseline 2* in Logan County. Appendix A contains figures for Logan County that show the changes between the profit distributions of affected production as well as affected and compensated production. The results for Logan County are consistent with those for Weld County.

CHAPTER 5: CONCLUSIONS AND LIMITATIONS

This research quantifies and describes profit risk that producers face when altering their cropping systems in order to conserve consumptive water use --- water that might be leased from farmer to other users. One objective is to compare the foregone profits of alternative cropping systems that conserve consumptive water use to a baseline system. These foregone profits are an opportunity cost to the farmer incurred as a result of adjusting the cropping system.

An important facet of this study is to incorporate risk into the measurement of potentially forgone profits. The risks that are considered include variation in prices and yields. A simulation model is developed and the historical data generation process is used as a foundation for model iterations in order to calculate profits for the baseline and alternative cropping systems. Multiple model iterations are executed, and the resulting profits collected to form a frequency. Analysis of these frequencies provides insights into the risk-return tradeoffs of various cropping systems and the potentially forgone profits.

Analysis is focused on three criteria: the “average” profit difference between baseline cropping systems and the alternatives; the lower “tail” of a cumulative frequency that represents the likelihood of poor profit outcomes; and the foregone opportunity of achieving high profits when prices and/or yields are strong.

Analyses of results suggest *Cropping System A* generates the lowest foregone profits when compared to other cropping systems. This is the case since *Cropping System A* retains the greatest level of irrigated corn compared to other systems. Since irrigated corn has high yields and high prices, substituting another crop into the rotation does not outweigh the benefits of growing corn. This suggests that the lowest compensation payment would be required by a producer for water conserved if they employ *Cropping System A* when entering a water leasing agreement. Given that a $28/AF of CU compensation payment is provided with *Cropping System A*, it soon becomes as attractive as the baseline in avoiding negative outcomes. The mean foregone profit for adopting *Cropping System A* spread over 2,000 acres is $ 58,472 when compared to Baseline. In addition, it should be noted that an increase in the negative foregone profit means the *Cropping System A* actually performed better than the Baseline system.

In general, the forgone profit values for *Cropping System A* are significantly lower than actual payments currently in place on other water leasing projects in Colorado. In fact, these calculated compensation values fall below those reported by Pritchett, et. al from producer surveys. While it is known that profit risk is significantly reduced by switching from *Baseline* to *Cropping System A*, compensation payment as well as producer risk preference are key in identifying producers' willingness to participate in a water leasing agreement. Provided that with a water leasing option, producers may decide to switch to a cropping mix similar to *Cropping System A*, another study might want to consider the impacts of such change on the rural communities that have businesses tied to the agricultural production.

When it comes to variation in profits, fallowing a portion of the system and devoting irrigation to corn acres appears to be the least risky. Adding another crop to the mix, in this case alfalfa, did not reduce the overall variability relative to a fallowing situation. Of course, fallowing may also create cash flow challenges for the farming operation. Indeed, the foregone mean profits ranged from a low of $ 58,472 for *Cropping System A* to $ 273,229 for *Cropping System C ,* with the $28 payment per afrefoot CU, which is a substantial reduction in cash flow.

Many research questions are left to consider and explore. One research question is how the structure of the compensation payment will influence profit risk and producers willingness to participate. One option payment scheme might include a base payment that is established from an historical average of forgone profits. Such payment, however, may not be the actual compensation needed by a producer in any given year. If the price and yields are high the year that producer chooses to lease water, they might miss out on high profits from crop production. In order to avoid giving away upside potential, a payment that is a function of yield and market price may be added post-harvest in addition to the initial base payment. In this case, producers reduce the downside risk by entering water leasing contract, yet preserve the high end profits in case the crop production is optimal that year.

A large number of limitations and assumptions are present in this study, which allows further research an opportunity to build and expand beyond what has been accomplished here. The simulation model is a one period model which only allows to capture the profits in a single year and compare profits between two cropping system in one year. Long run impacts to the production system, debt structure, debt payments and equity growth are not considered. The varieties of crops used in this study are limited. Irrigated and dry-land crops such as corn, winter wheat and alfalfa are included; however, dry beans, sugar beets, onions and corn for silage are not. Greater variety of crops might change the forgone profits; however, the crops used in this study account for more than 90% of irrigated cropping and dry-land alternatives in the South Platte. A representative farm is used in this analysis, and its tillage practices and other inputs are typical of the area. These practices are embedded in the enterprise budgets used in the empirical model. An individual farm's practices may differ.

Similarly, marketing of farm products is assumed to be at harvest, so farmers that sign pre-harvest contracts or store their commodities after harvest may realize different prices. Due to the absence of some local alfalfa prices, an estimation process using regression is implemented to forecast prices in appropriate years. Regressing local alfalfa prices on state average prices in the same month and then predicting missing values generates a close, though not exact estimate for the local alfalfa harvest month average prices. Of course, this study does not seek to predict the performance of cropping systems using exact prices; rather, the modeling effort seeks to represent the underlying price discovery process that includes an embedded correlation with local yields, national yields and national prices. All price factors mentioned above impact yearly profits and thus change the profit distribution.

Additionally, an assumption is made that the quality of soil is equivalent across the entire production site. This assumption is not realistic. Indeed, a producer that fallows land will choose to do so with the lower quality areas so the conserved consumptive use of water may be lower than expected and yields higher than expected.

Future research may consider extending the model to capture several years of production. Including a greater variety of crops would provide more information about the impacts on profits of changing production to different cropping systems. Hedonic valuation of irrigated and non-irrigated land leased may be used to arrive at the value of water in irrigated production. Using such value as a compensation amount would give better information to producers and stakeholders of how producers' profits are impacted.

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Troy Bauder, Neil Hansen and James Pritchett, (January, 2012) Expert Opinion

APPENDIX A

Weld County: ***Baseline 1***

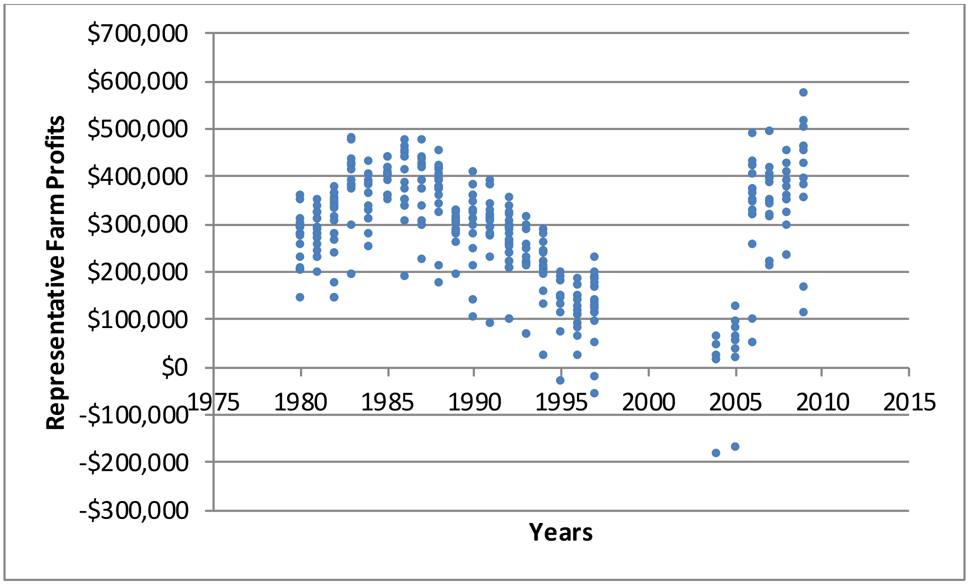

Figure 20: Adjusted Simulation Results of Profits vs. Years for the Baseline 1 in Weld County

Table 15: Summary Statistics of Profits for a Representative Farms for Weld County Baseline 1 All Simulated Data

STATISTICS	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	290,519	193,689	112,600	-39,029	103,081
St. Dev.	390,409	260,285	223,499	310,131	312,242
COV	134	134	198	-794	302
Min	-288,073	-192,058	-268,328	-452,181	-362,486
Max	2,063,254	1,375,572	1,162,592	1,275,567	1,408,026

Table 16: Summary Statistics of Profits for a Representative Farms for Weld County Baseline 1 Adjusted Data

STATISTICS	*Baseline 1*	*Cropping System A*	*Cropping System B*	*Cropping System C*	*Cropping System D*
Mean	285,522	190,357	113,172	-35,625	116,461
St. Dev.	118,254	78,840	83,988	118,659	125,568
COV	41	41	74	-333	108
Min	-181,317	-120,884	-111,788	-441,059	-286,183
Max	578,211	385,493	427,664	227,808	443,414

Table 17: Summary Statistics of Potentially Forgone Profits $/CU for a Representative Farm for Weld County Baseline 1 Adjusted Data

	Potentially Forgone Profits $/CU			
STATISTICS	*Cropping System A*	*Cropping System B*	*Cropping System C*	*Cropping System D*
Mean	119	605	269	384
St. Dev.	49	339	79	200
COV	41	56	29	52
Min	-76	-438	110	-174
Max	242	1,411	521	1,122

Table 18: Summary Statistics of Potentially Forgone Profits $/Dry Acre for a Representative Farm for Weld County Baseline 1 Adjusted Data

	Potentially Forgone Profits $/Acre			
STATISTICS	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	143	129	321	169
St. Dev.	59	72	94	88
COV	41	56	29	52
Min	-91	-94	131	-76
Max	289	301	622	494

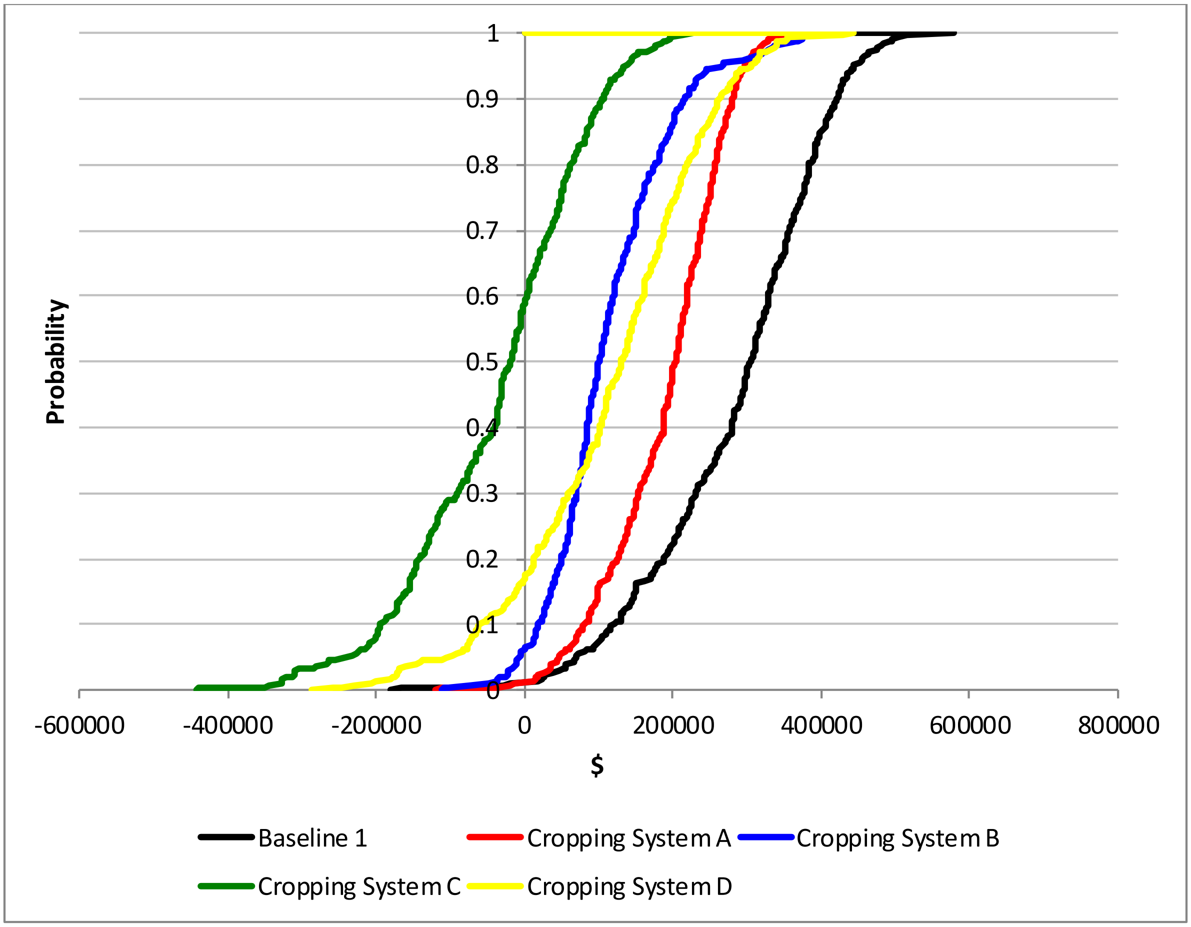

Figure 21: Cumulative Distribution Functions for Baseline 1 and the Four Alternative Cropping Systems for Weld County

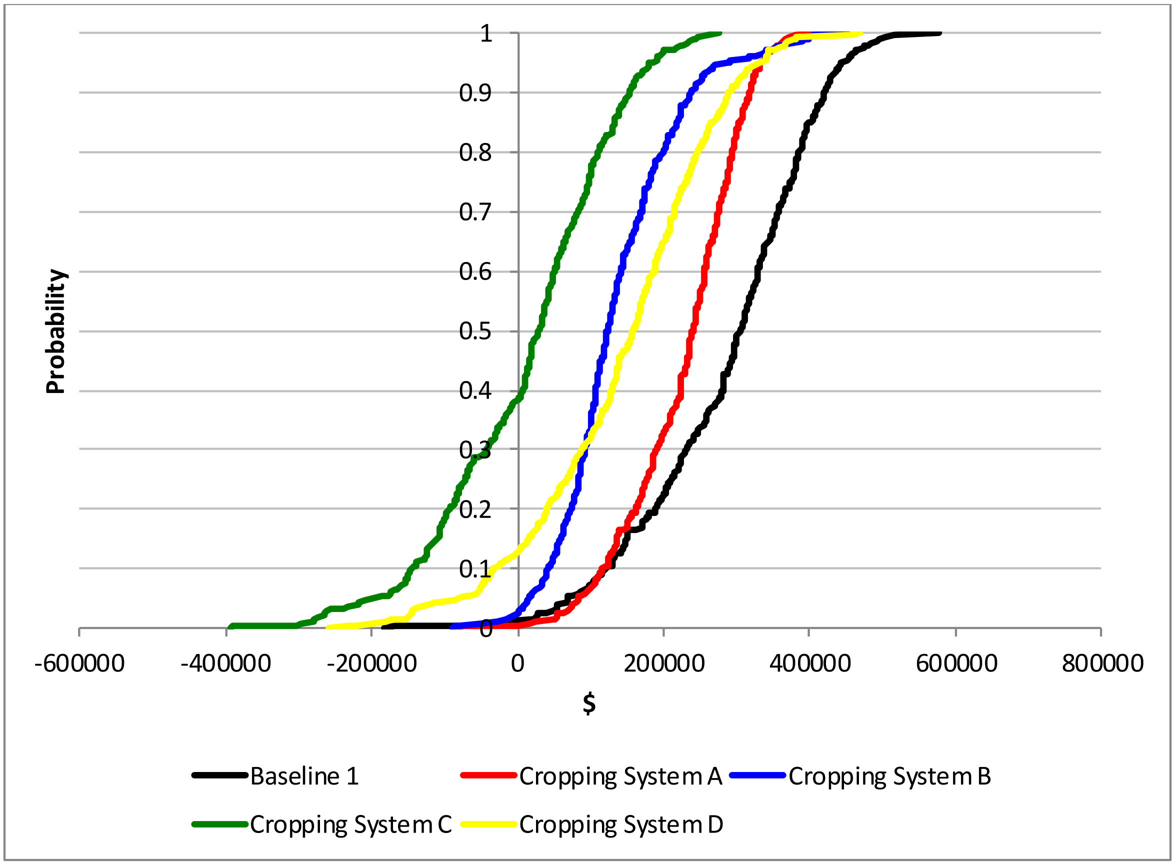

Figure 22: Cumulative Distribution Functions for Baseline 1 with $ 28 Payment per unit CU for Weld County

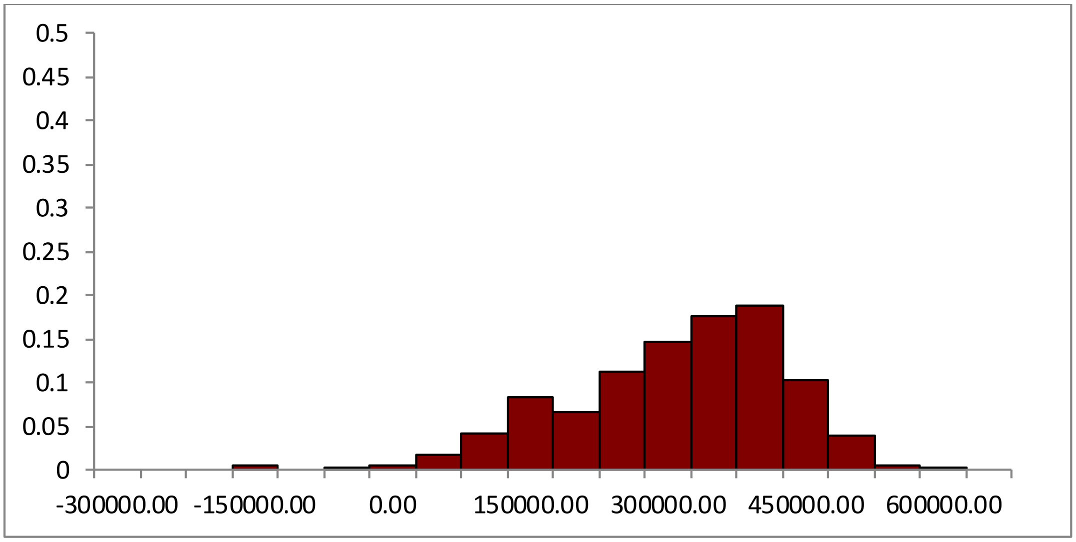

Figure 23: Profits for Baseline 1 Weld County

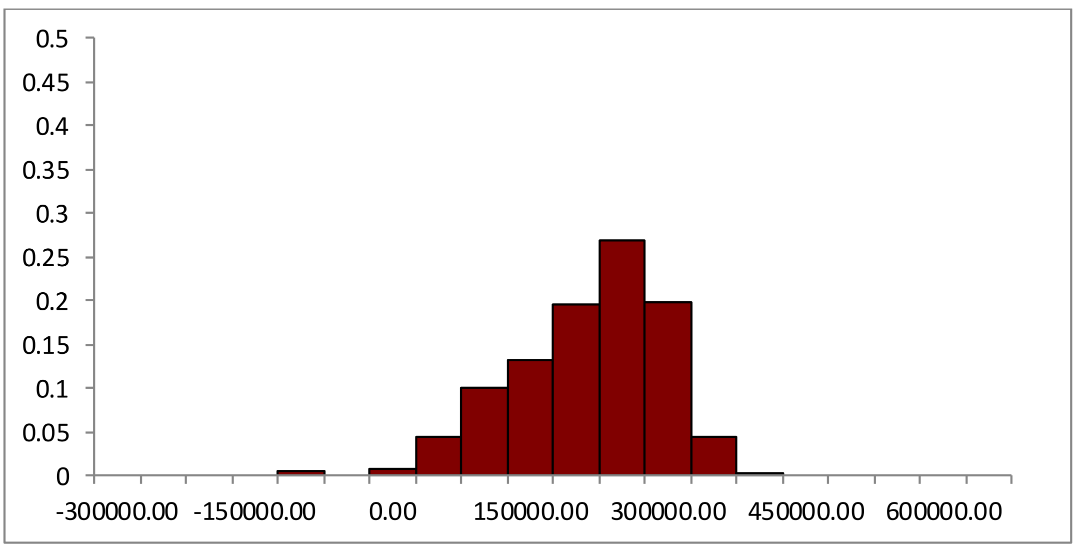

Figure 24: Profits for Cropping System A Weld County Baseline 1

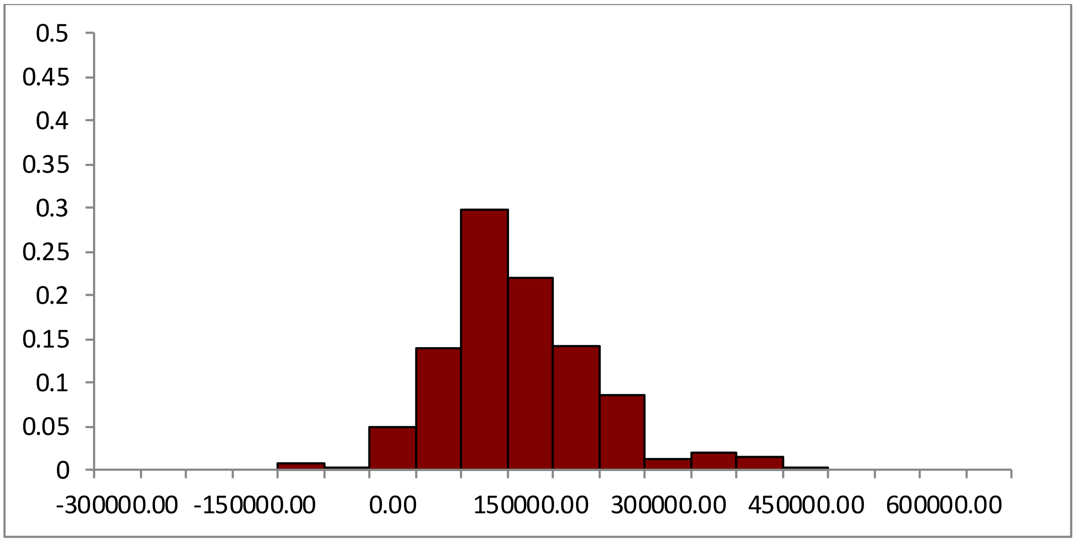

Figure 25: Profits for Cropping System B Weld County Baseline 1

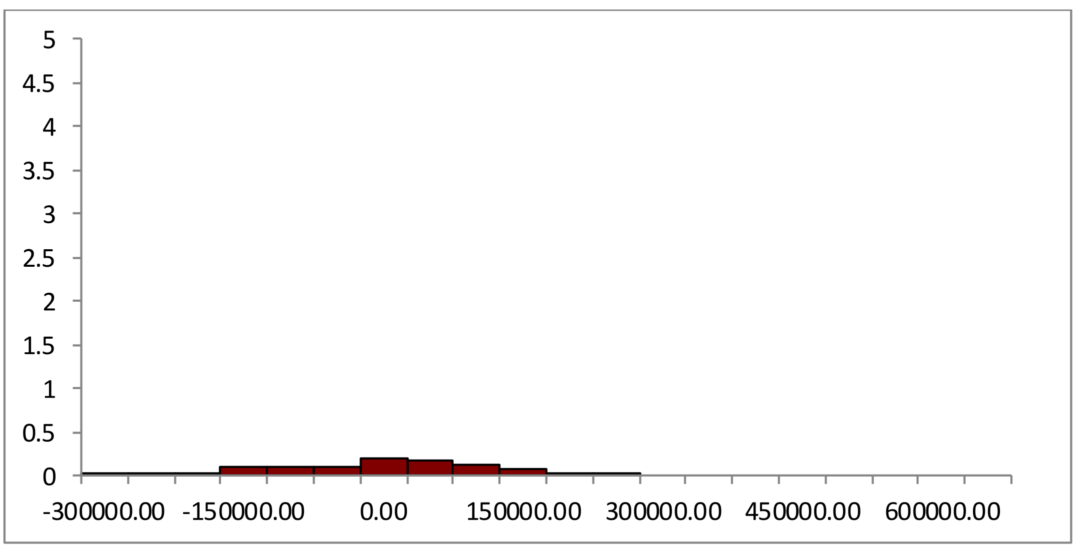

Figure 26: Profits for Cropping System C Weld County Baseline 1

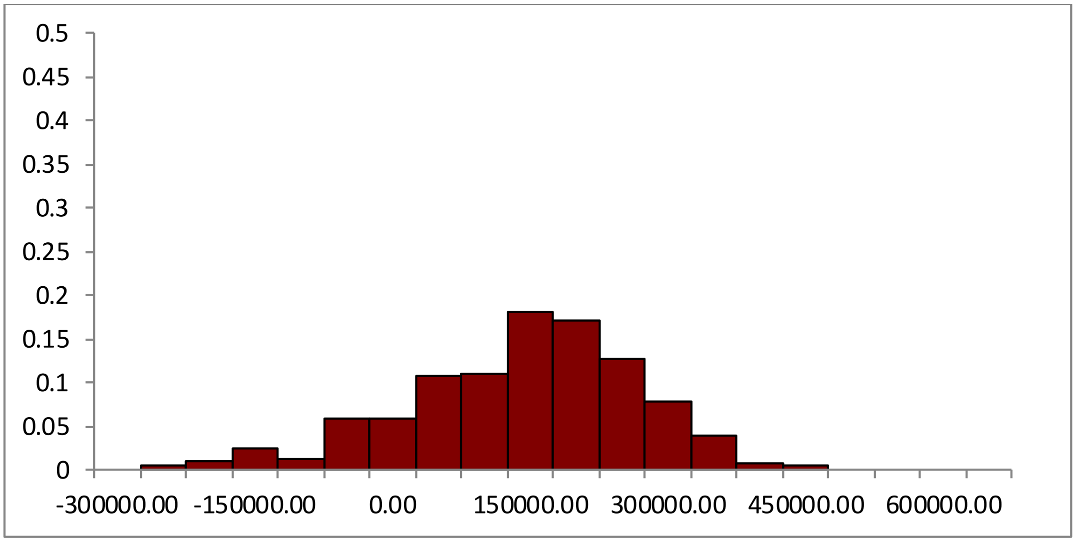

Figure 27: Profits for Cropping System D Weld County Baseline 1

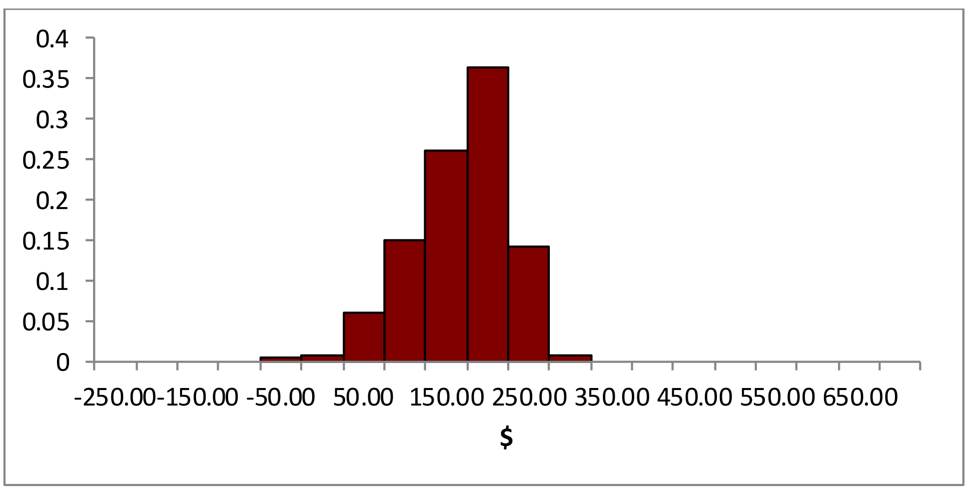

Figure 28: $/Acre Potentially Forgone Profits Cropping System A Weld County Baseline 1

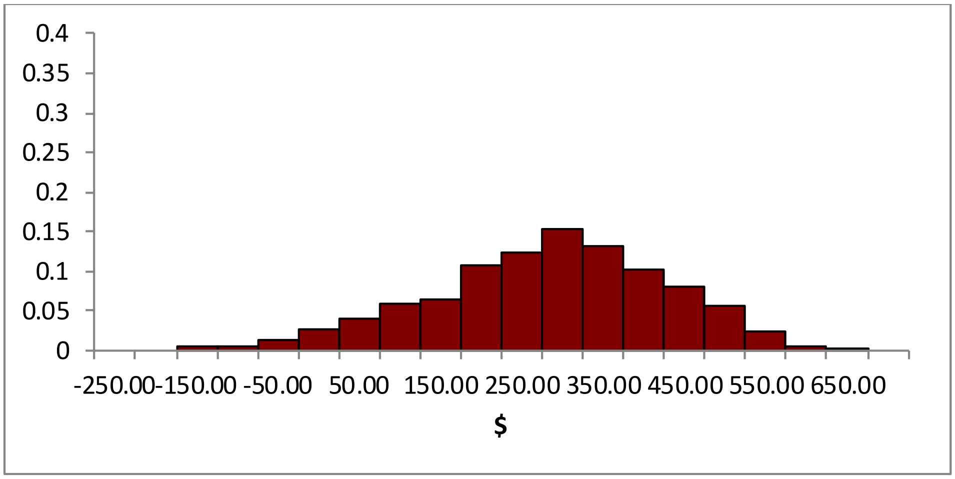

Figure 29: $/Acre Potentially Forgone Profits Cropping System B Weld County Baseline 1

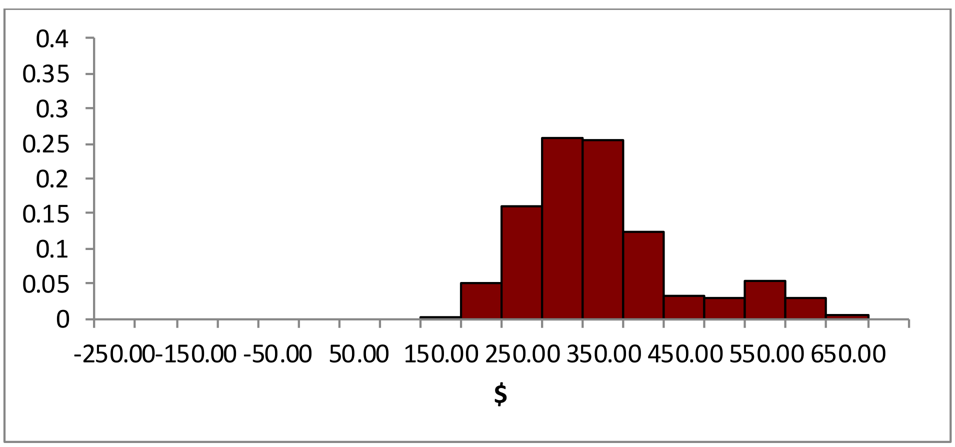

Figure 30: $/Acre Potentially Forgone Profits Cropping System C Weld County Baseline 1

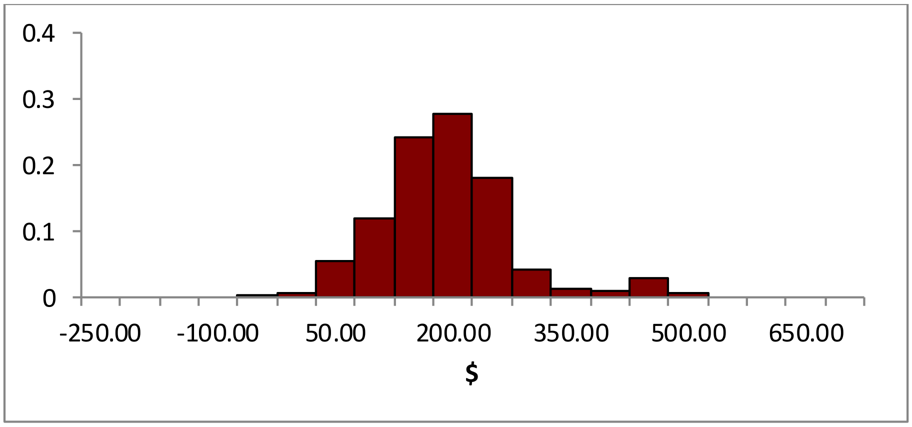

Figure 31: $/Acre Potentially Forgone Profits Cropping System D Weld County Baseline 1

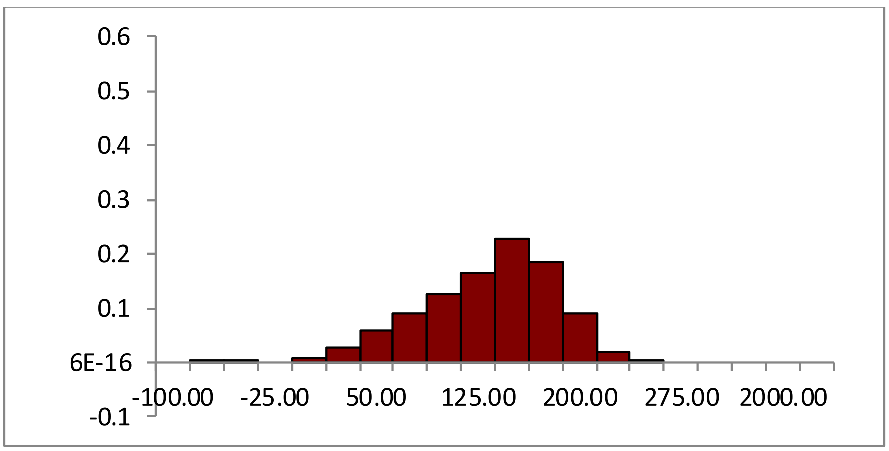

Figure 32: $/CU Potentially Forgone Profits Cropping System A Weld County Baseline 1

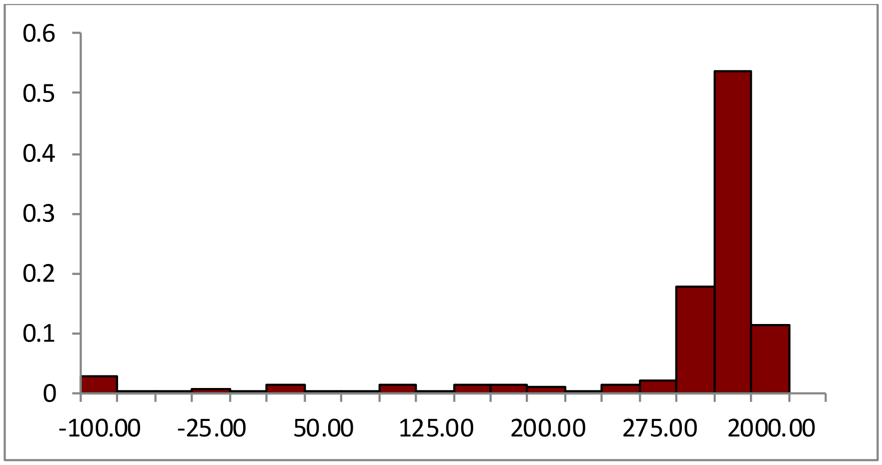

Figure 33: $/CU Potentially Forgone Profits Cropping System B Weld County Baseline 1

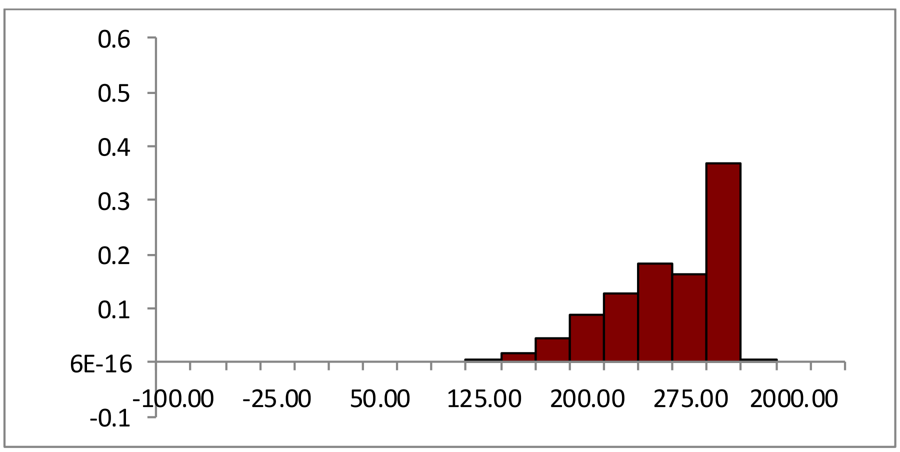

Figure 34: $/CU Potentially Forgone Profits Cropping System C Weld County Baseline 1

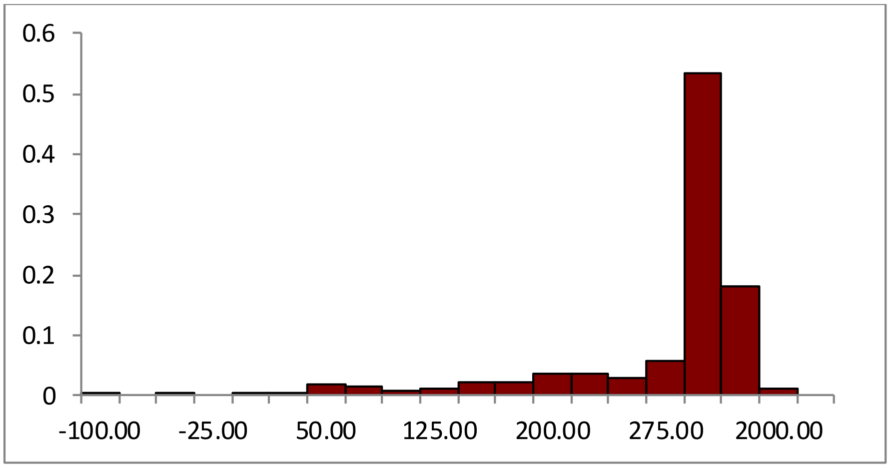

Figure 35: $/CU Potentially Forgone Profits Cropping System D Weld County Baseline 1

Weld County: ***Baseline 2***

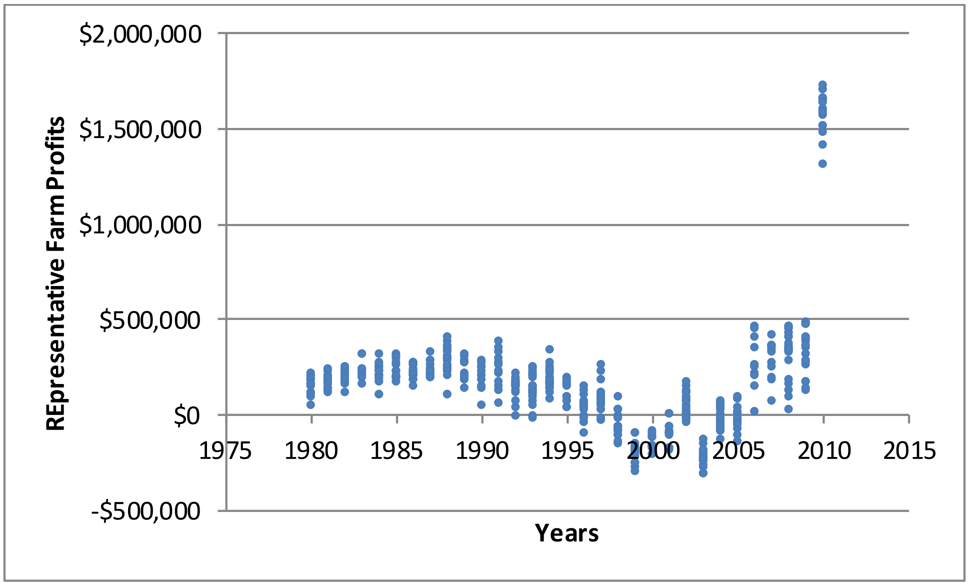

Figure 36: All Simulation Results of Profits vs. Years for the Baseline 2 in Weld County

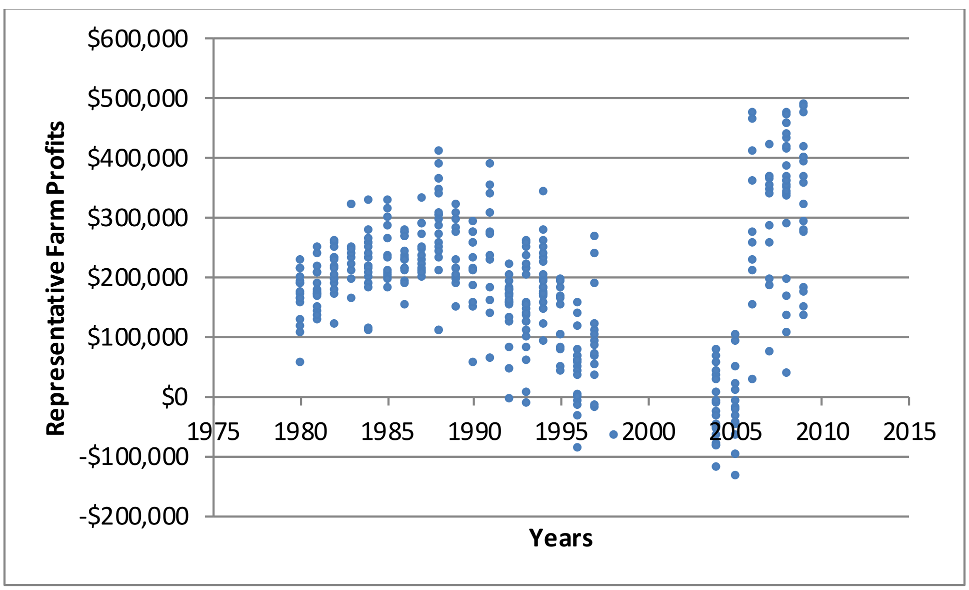

Figure 37: Adjusted Simulation Results of Profits vs. Years for the Baseline 2 in Weld County

Table 19: Summary Statistics of Profits for a Representative Farms for Weld County Baseline 2 All Simulated Data

STATISTICS	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	173,568	170,358	88,297	-69,815	74,852
St. Dev.	308,058	228,631	197,609	275,376	279,768
COV	177	134	224	-394	374
Min	-301,325	-169,628	-241,943	-460,943	-372,481
Max	1,730,754	1,335,667	1,103,589	1,292,055	1,369,403

Table 20: Summary Statistics of Profits for a Representative Farms for Weld County Baseline 2 Adjusted Data

STATISTICS	***Baseline 2***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	191,520	182,223	100,305	-49,799	104,272
St. Dev.	121,313	87,169	87,287	130,469	141,108
COV	63	48	87	-262	135
Min	-134,176	-49,016	-129,296	-387,160	-269,883
Max	491,840	376,528	354,591	196,607	426,827

Table 21: Summary Statistics of Potentially Forgone Profits $/CU for a Representative Farm for Weld County Baseline 2 Adjusted Data

	Potentially Forgone Profits $/CU			
STATISTICS	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	7	114	141	91
St. Dev.	50	55	71	113
COV	709	48	50	124
Min	-99	-31	2	-182
Max	193	236	397	545

Table 22: Summary Statistics of Potentially Forgone Profits $/Dry Acre for a Representative Farm for Weld County Baseline 2 Adjusted Data

	Potentially Forgone Profits $/Acre			
STATISTICS	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	14	137	241	87
St. Dev.	99	65	122	108
COV	709	48	50	124
Min	-195	-37	3	-173
Max	379	283	678	520

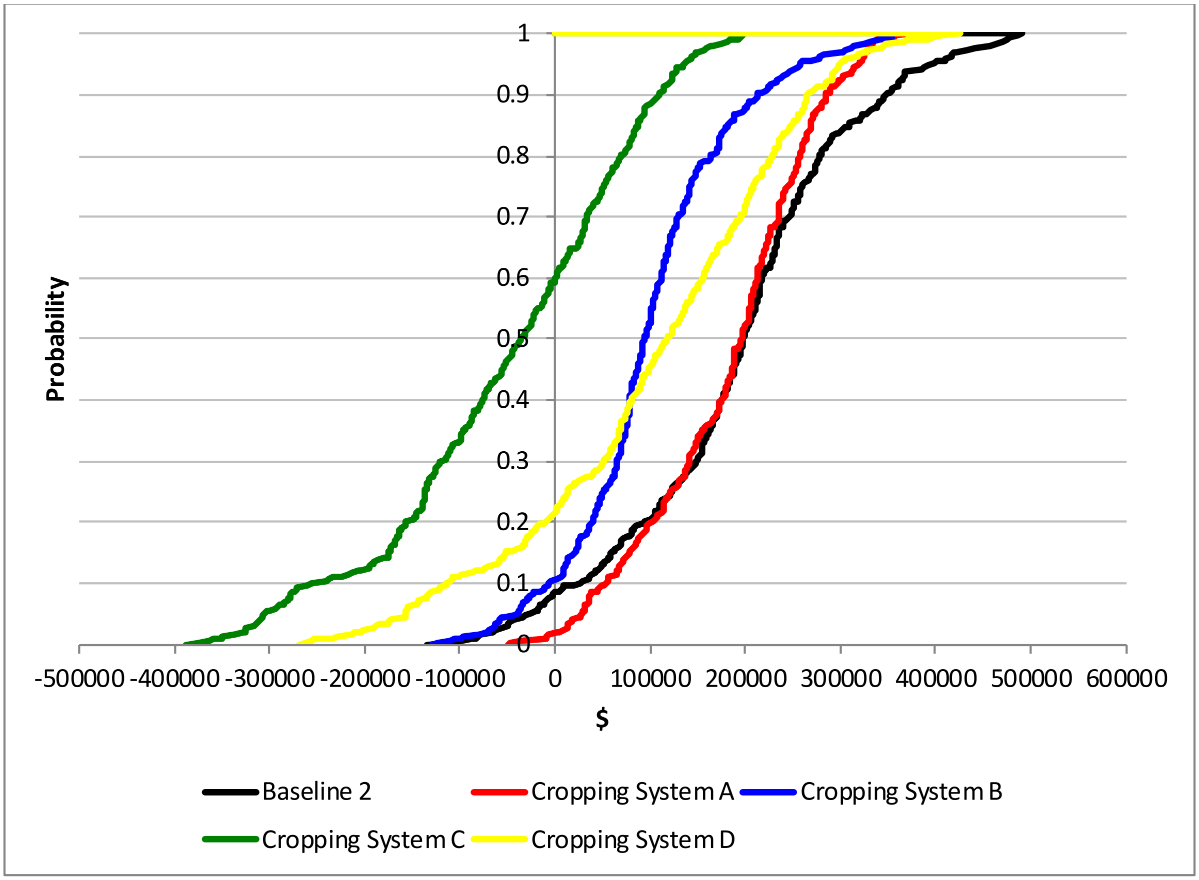

Figure 38: Cumulative Distribution Functions for Baseline 2 and the Four Alternative Cropping Systems for Weld County

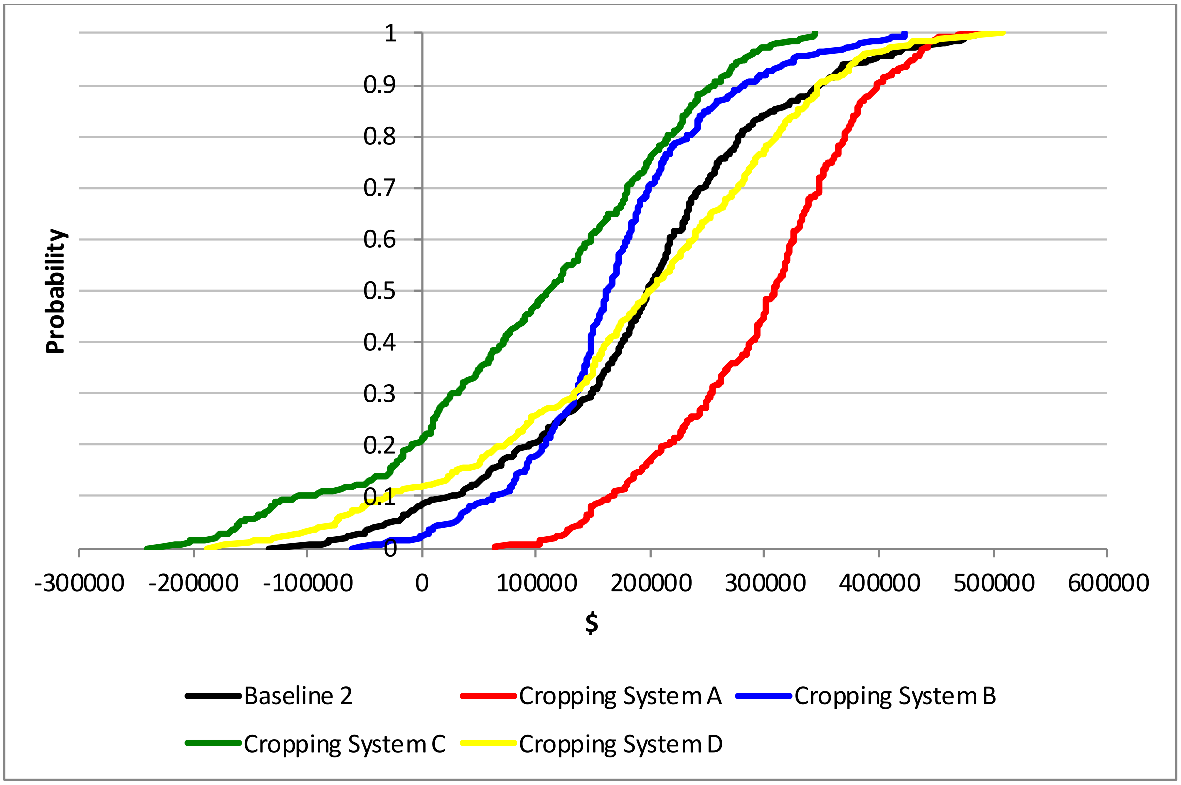

Figure 39: Cumulative Distribution Functions for Baseline 2 and the Four Alternative Cropping Systems with $28/Acre Foot CU Payment for Weld County

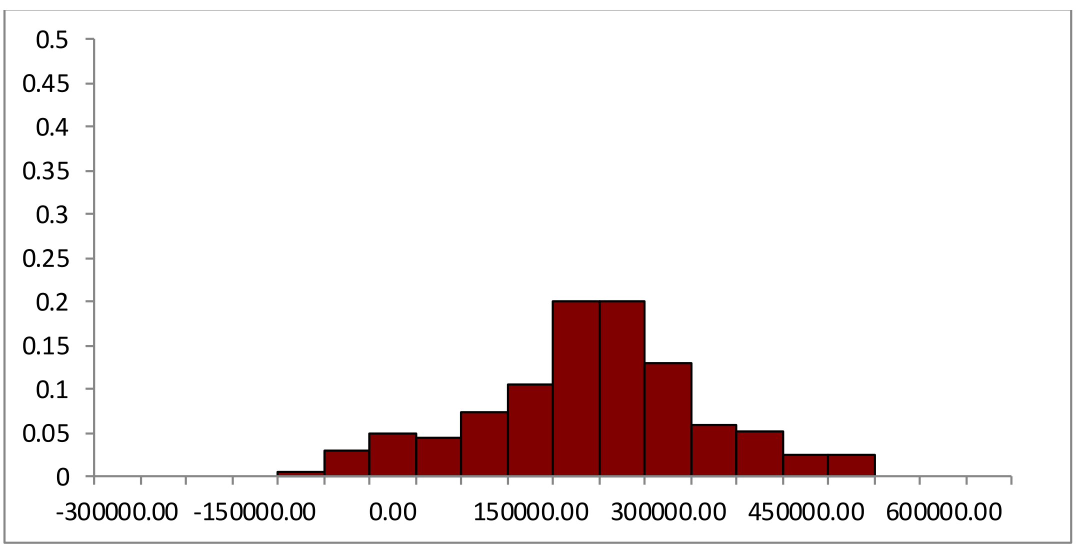

Figure 40: Profits for Weld County Baseline 2

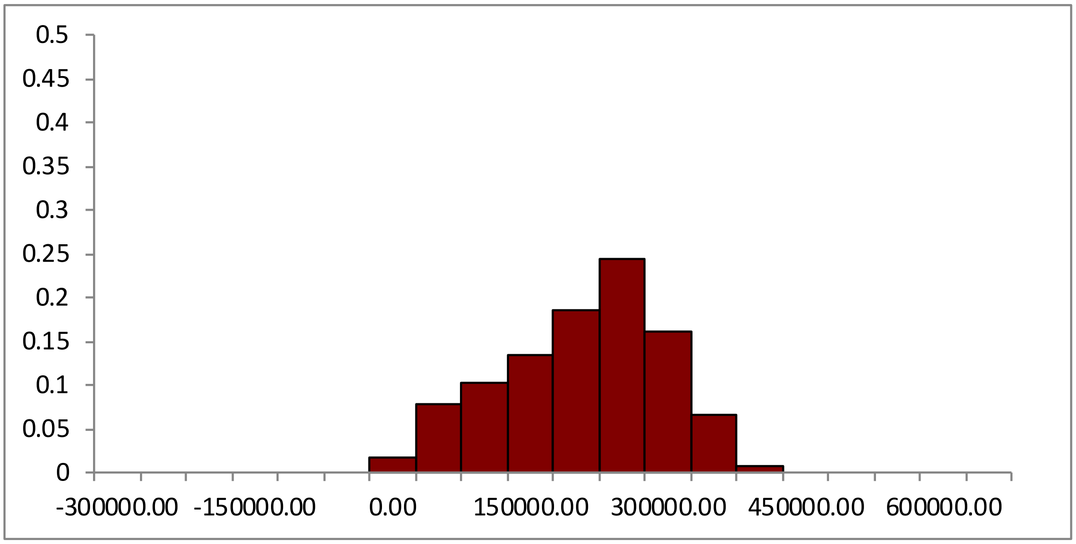

Figure 41: Profits for Cropping System A Weld County Baseline 2

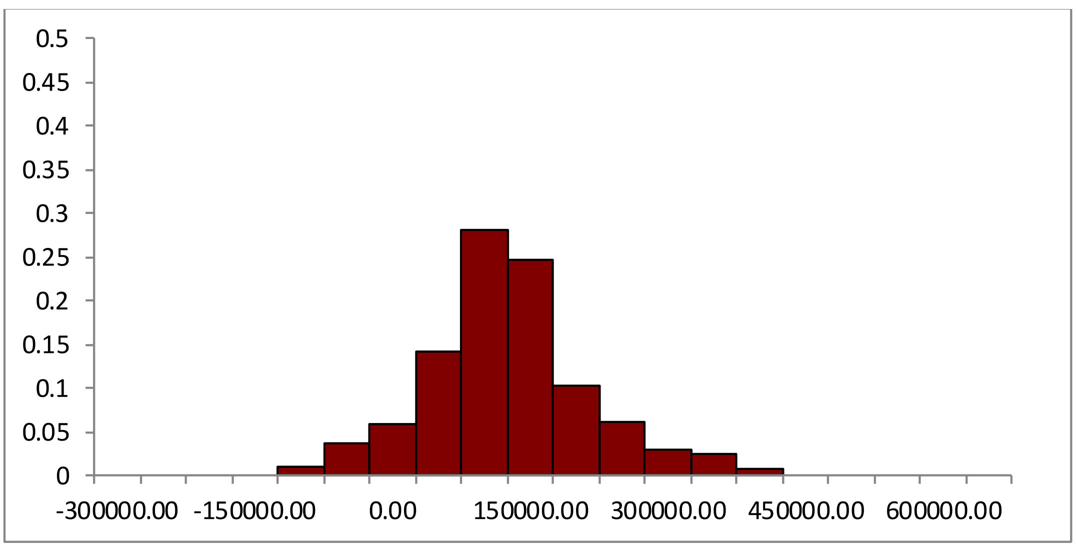

Figure 42: Profits for Cropping System B Weld County Baseline 2

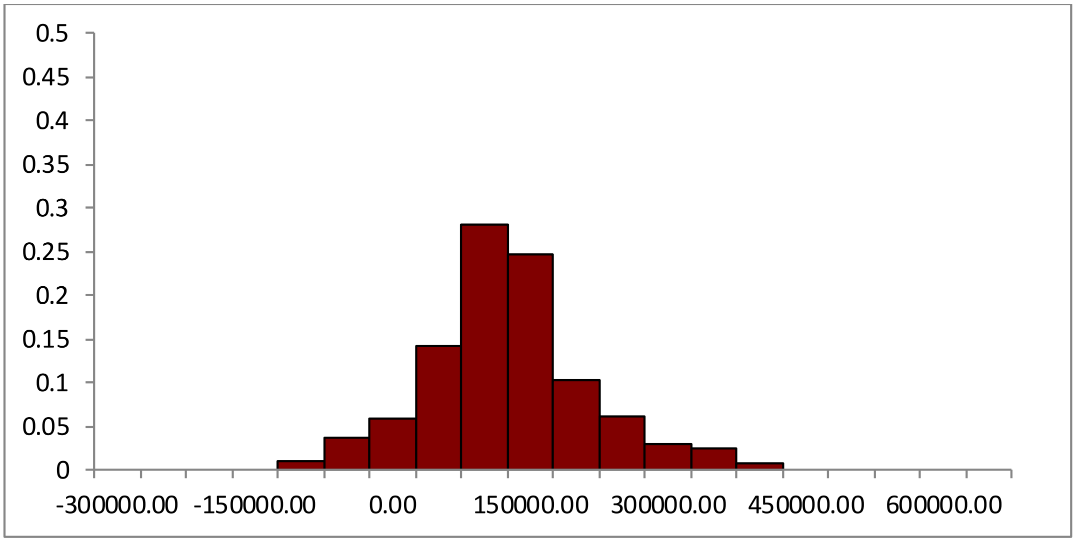

Figure 43: Profits for Cropping System C Weld County Baseline 2

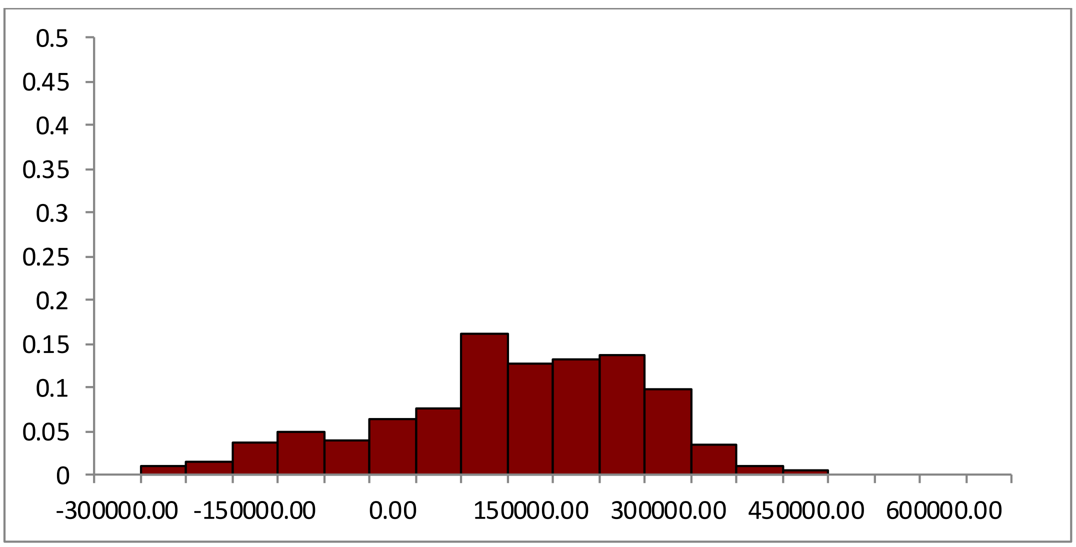

Figure 44: Profits for Cropping System D Weld County Baseline 2

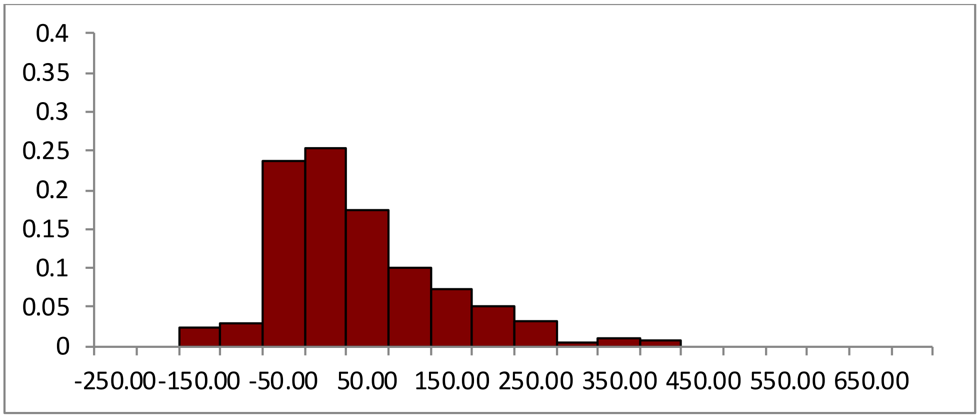

Figure 45: $/Acre Potentially Forgone Profits Cropping System A Weld County Baseline 2

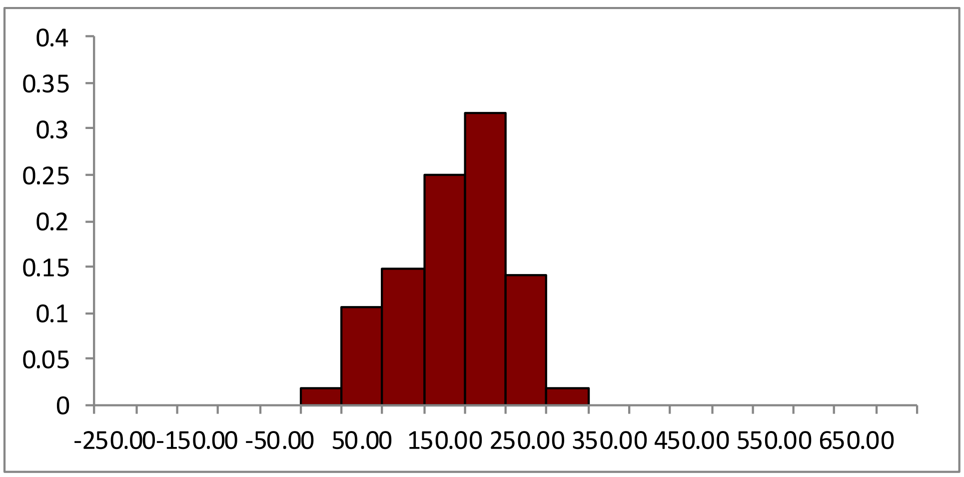

Figure 46: $/Acre Potentially Forgone Profits Cropping System B Weld County Baseline 2

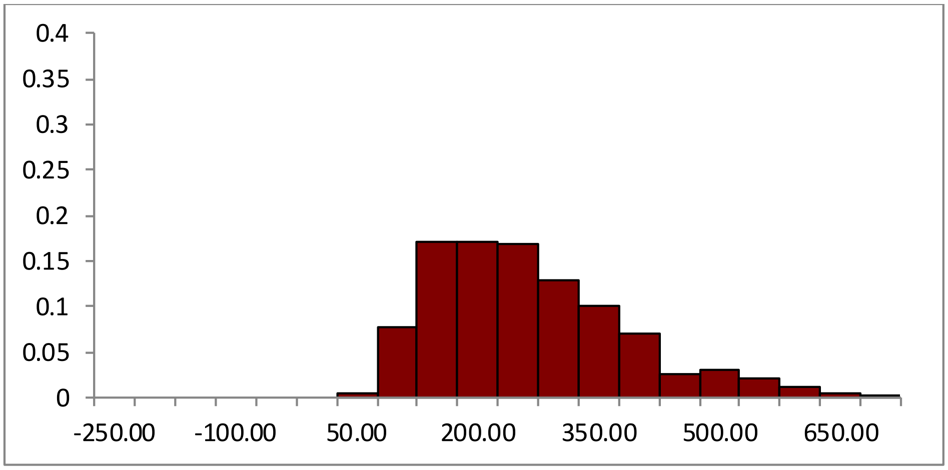

Figure 47: $/Acre Potentially Forgone Profits Cropping System C Weld County Baseline 2

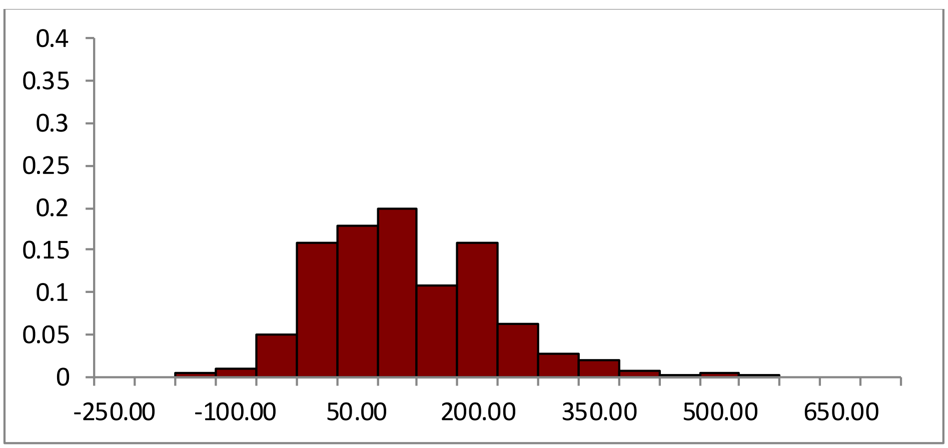

Figure 48: $/Acre Potentially Forgone Profits Cropping System D Weld County Baseline 2

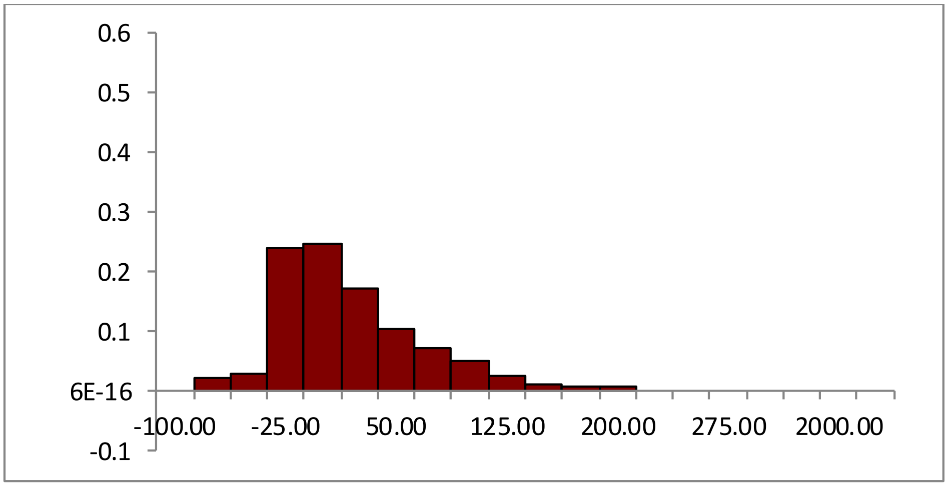

Figure 49: $/CU Potentially Forgone Profits Cropping System A Weld County Baseline 2

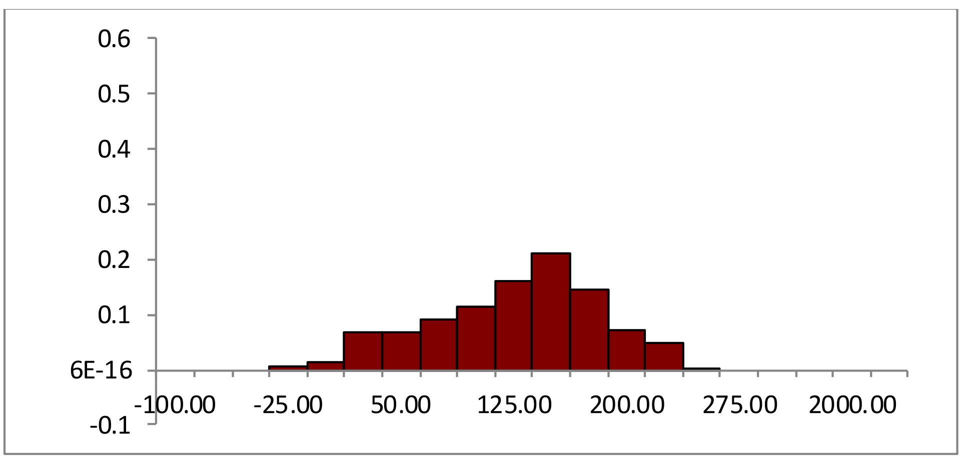

Figure 50: $/CU Potentially Forgone Profits Cropping System B Weld County Baseline 2

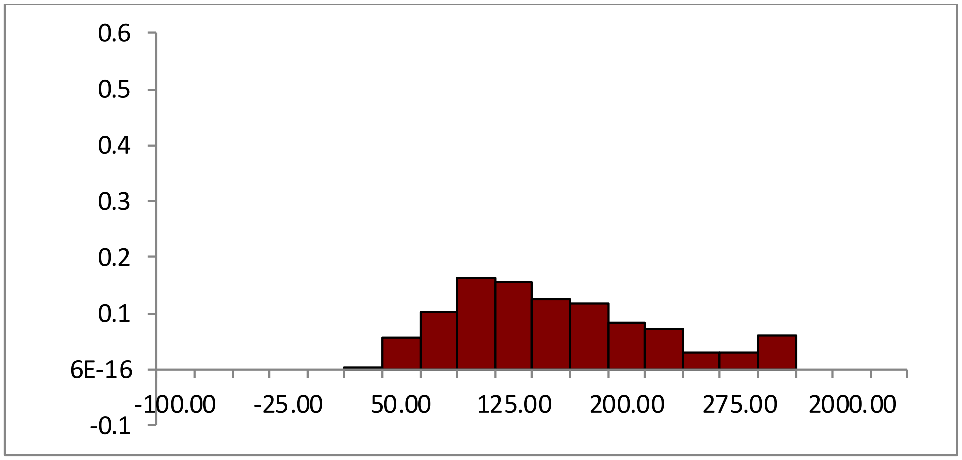

Figure 51: $/CU Potentially Forgone Profits Cropping System C Weld County Baseline 2

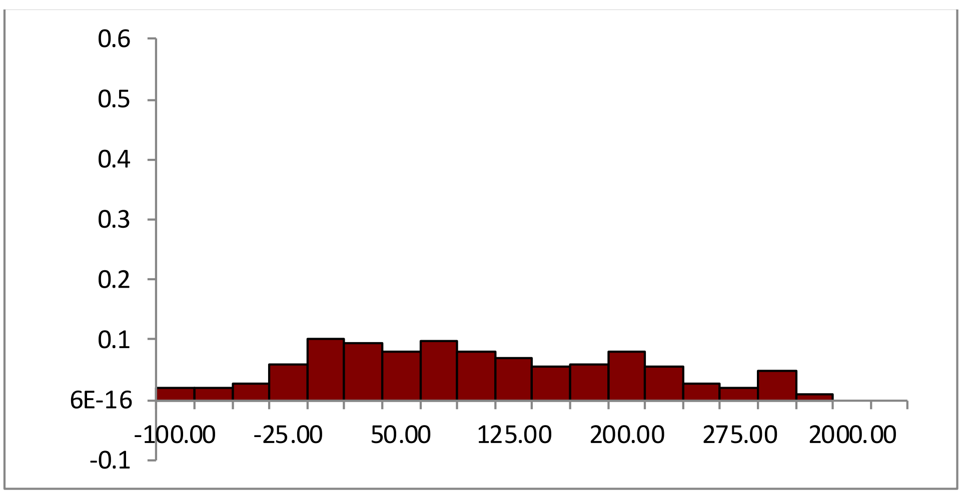

Figure 52: $/CU Potentially Forgone Profits Cropping System D Weld County Baseline 2

Table 23: Frequency of Iterations with Mean Equivalence Payment Weld County *Baseline 2*

Frequency of Iterations with Mean Equivalence Payment Weld County *Baseline 2*					
***Baseline 2* Mean Profit = $191,520**	***Baseline 2***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Profit < Baseline2 Mean Profit	45.62%	42.53%	52.06%	45.36%	62.89%
Profit < 10 % below Baseline2 Mean Profit	37.89%	35.57%	41.75%	41.24%	57.47%
Profit < 20 % below Baseline2 Mean Profit	30.41%	30.93%	27.06%	35.82%	53.87%
Profit > Baseline2 Mean Profit	52.06%	55.15%	45.62%	52.32%	34.79%
Profit > 10 % above Baseline2 Mean Profit	43.30%	46.39%	33.76%	47.68%	28.61%
Profit > 20 % above Baseline2 Mean Profit	35.31%	35.57%	26.29%	43.30%	22.16%
Profit < 0	8.25%	1.55%	1.55%	10.05%	19.33%

Logan County: *Baseline 1*

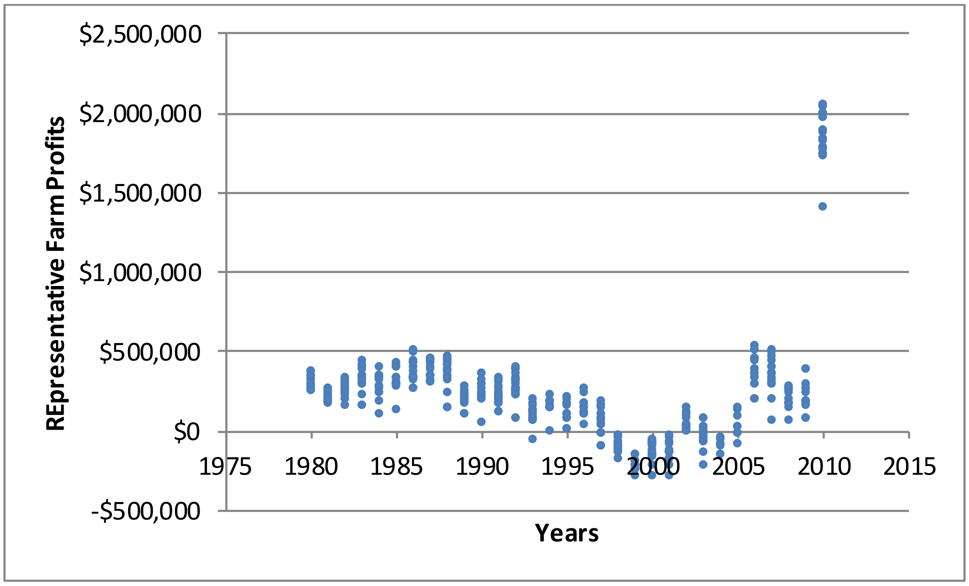

Figure 53: Simulation Results of Profits vs. Years in Logan County for the Baseline 1

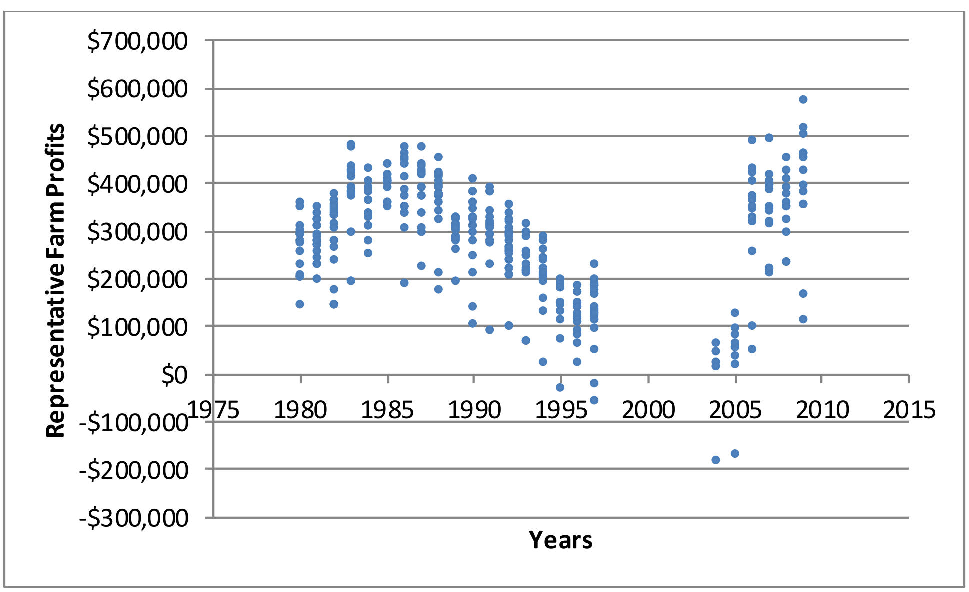

Figure 54: Adjusted Simulation Results of Profits vs. Years in Logan County for the Baseline 1

Table 24: Summary Statistics of Profits for a Representative Farms for Logan County Baseline 1 All Simulated Data

STATISTICS	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	261,232	174,163	108,125	-46,961	38,427
St. Dev.	394,742	263,174	226,003	310,068	310,315
COV	151	151	209	-660	808
Min	-279,620	-186,423	-256,687	-473,948	-449,722
Max	2,058,847	1,372,633	1,129,786	1,334,800	1,323,763

Table 25: Summary Statistics of Profits for a Representative Farm for Logan County Baseline 1 Adjusted Data

STATISTICS	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	250,483	166,997	100,244	-45,889	44,593
St. Dev.	126,541	84,365	76,906	119,740	125,462
COV	51	51	77	-261	281
Min	-145,074	-96,721	-147,250	-391,987	-348,675
Max	547,408	364,957	352,524	184,271	323,776

Table 26: Summary Statistics of Potentially Forgone Profits $/CU for a Representative Farm for Logan County Baseline 1 Adjusted Data

	Potentially Foregone Profits $/CU			
STATISTICS	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	105	527	248	468
St. Dev.	53	362	82	219
COV	51	69	33	47
Min	-61	-478	81	-103
Max	229	1,454	524	1,310

Table 27: Summary Statistics of Potentially Foregone Profits $/Dry Acre for a Representative Farm for Logan County Baseline 1 Adjusted Data

	Potentially Forgone Profits $/Acre			
STATISTICS	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	125	225	296	206
St. Dev.	63	155	97	96
COV	51	69	33	47
Min	-73	-204	97	-45
Max	274	621	626	576

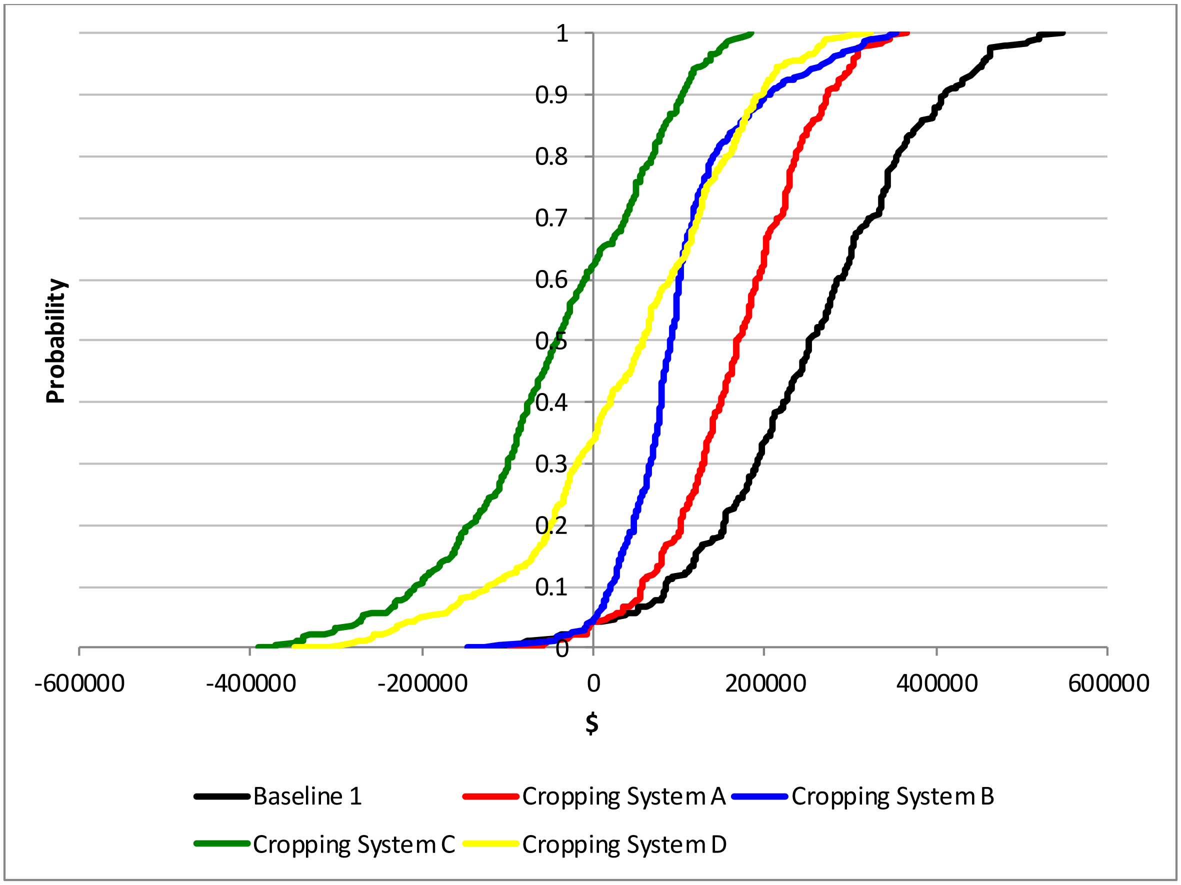

Figure 55: Cumulative Distribution Frequencies for Logan County, Baseline 1

Table 28: Important Values from the CDF for Logan County, Baseline 1

LOGAN	*Baseline 1*	*Cropping System A*	*Cropping System B*	*Cropping System C*	*Cropping System D*
50%	$251,096	$167,406	$89,860	-$41,582	$57,372
Profit < $0	4.00%	4.00%	4.00%	62.40%	33.60%
Profit > $250,000	52%	15%	6%	0%	3%

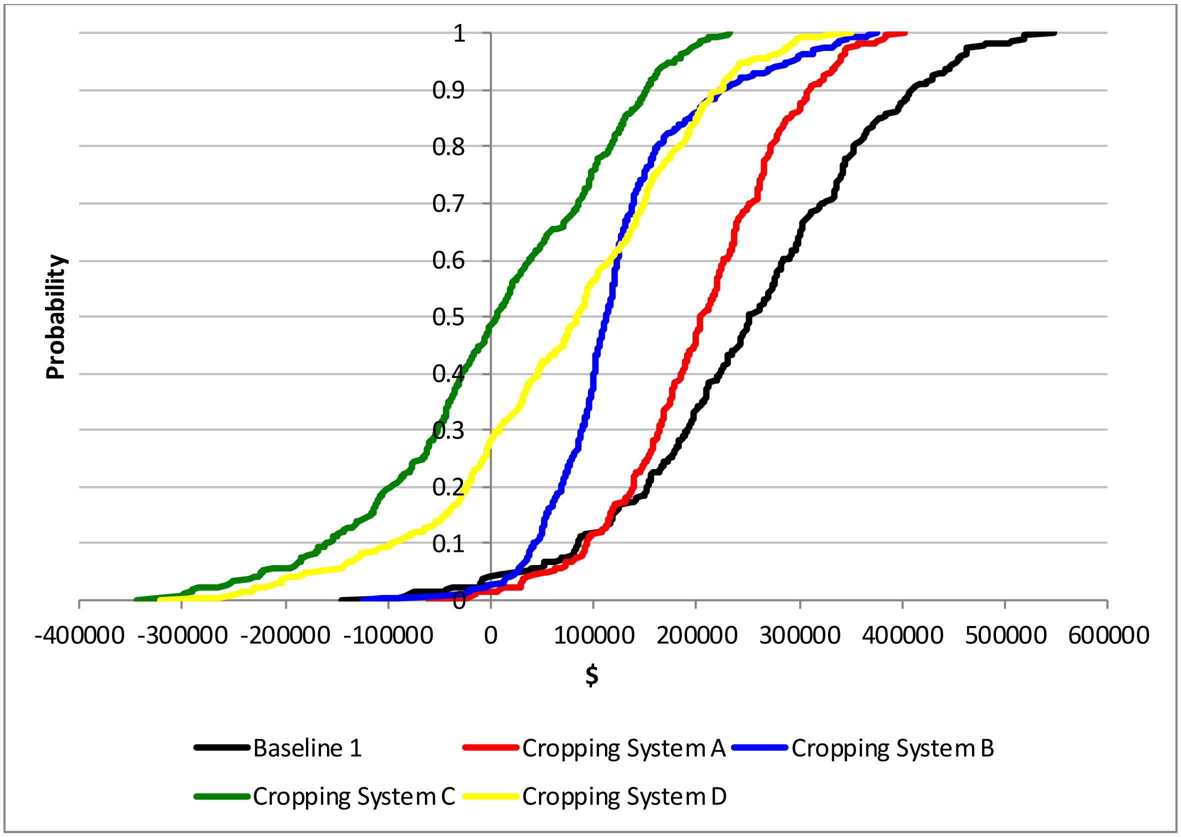

Figure 56: Cumulative Distribution Frequencies for Logan County Baseline 1 with a $28 Payment per acre foot CU

Table 29: Important Values from the CDF for Logan County Baseline 1 with a $28 Payment per acre foot CU

LOGAN (w/ $28)	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
50%	$251,096	$204,098	$112,225	$6,266	$84,080
Profit < $0	4.00%	1.30%	2.60%	48.40%	28.04%
Profit > $250,000	52%	30%	8%	0%	3%

Table 30: With and Without payment Profit Comparison

Baseline 1 LOGAN	Total Mean Profit ($)			
	Cropping System A	*Cropping System B*	*Cropping System C*	*Cropping System D*
w/out payment	$166,997	$100,244	-$45,889	$44,593
w/ $ 28.00 payment	$203,686	$122,605	$1,956	$71,297

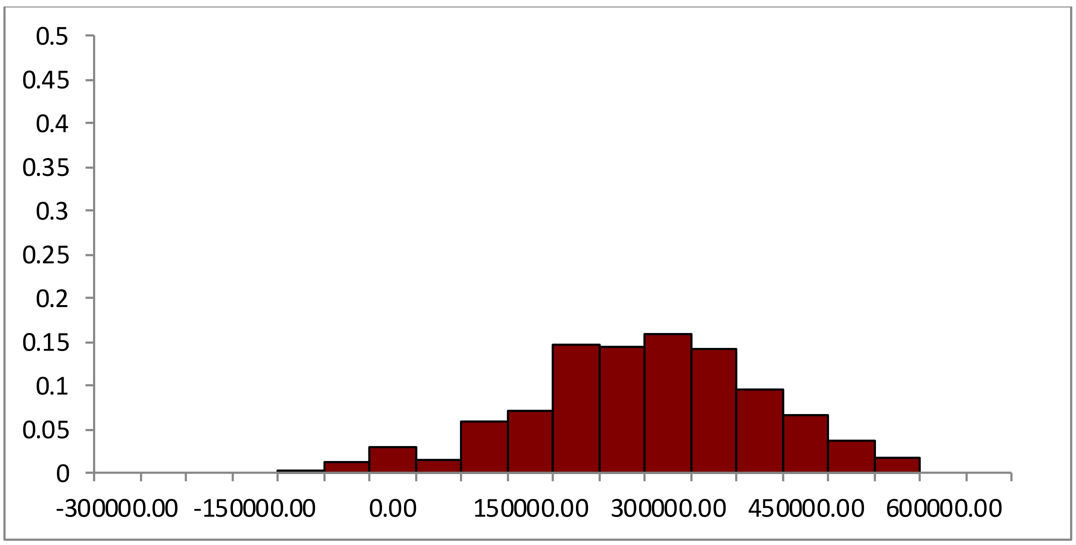

Figure 57: Profit for Logan County Baseline 1

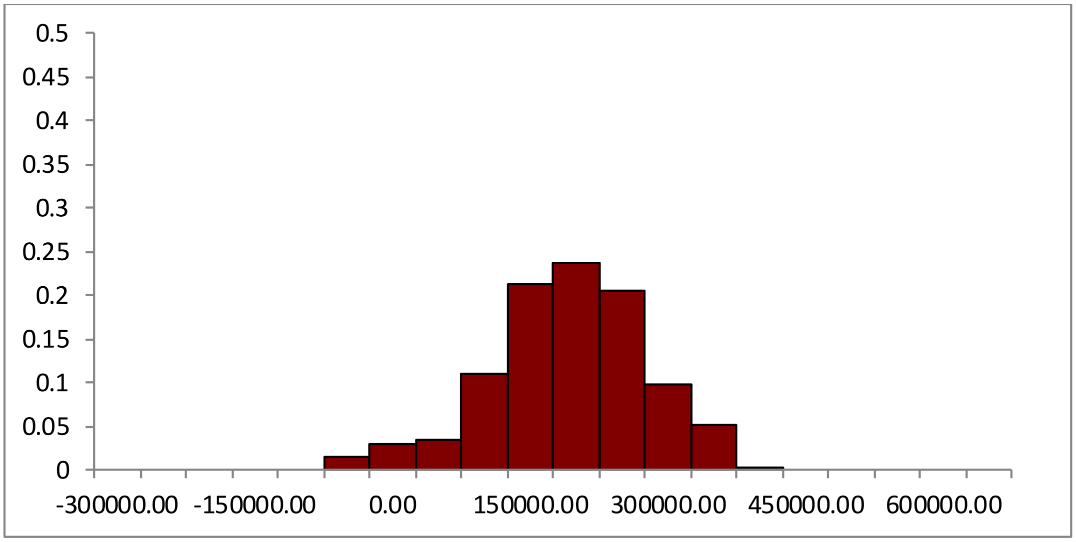

Figure 58: Profit for Cropping System A Logan County, Baseline 1

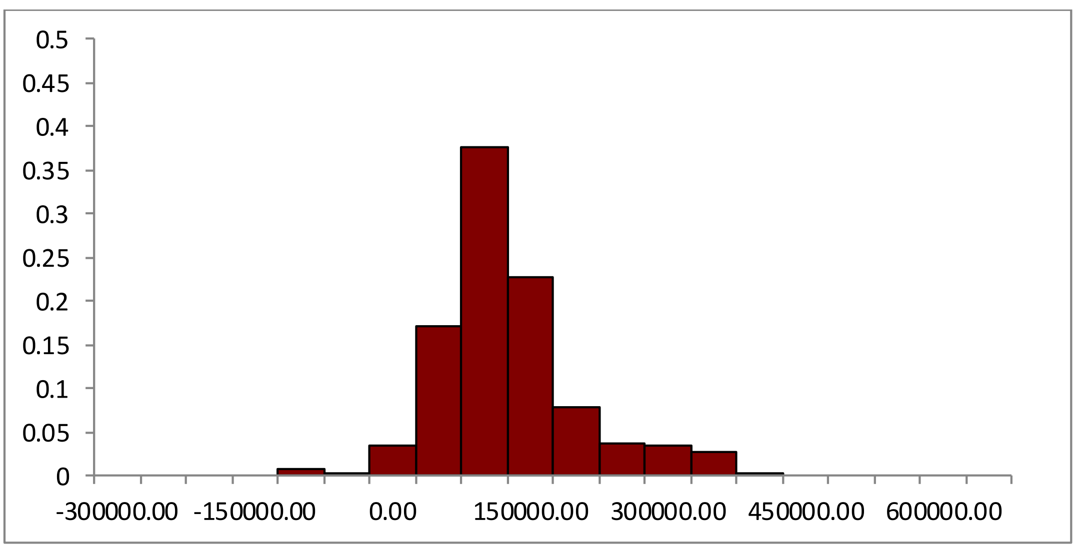

Figure 59: Profit for Cropping System B Logan County, Baseline 1

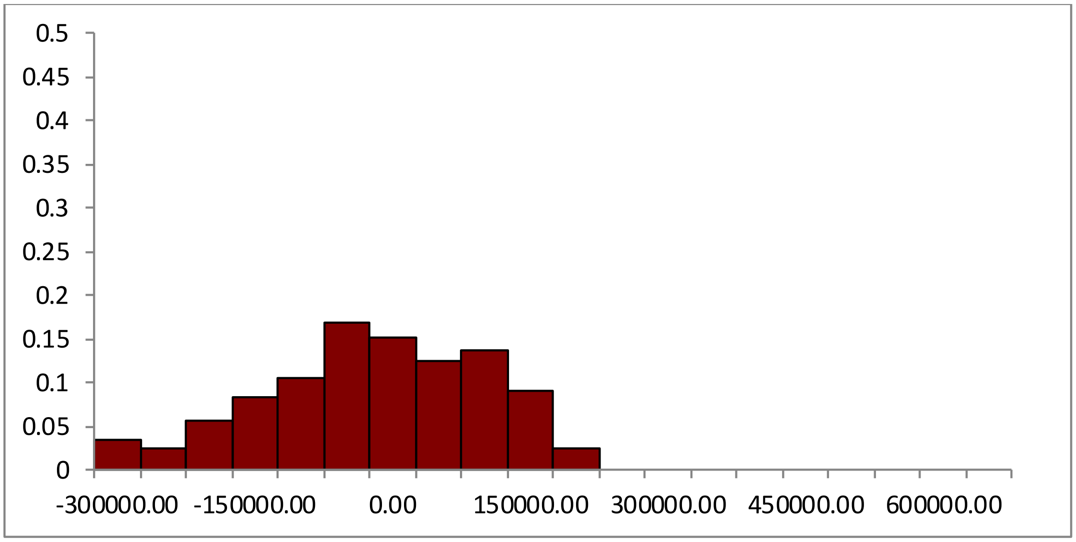

Figure 60: Profit for Cropping System C Logan County, Baseline 1

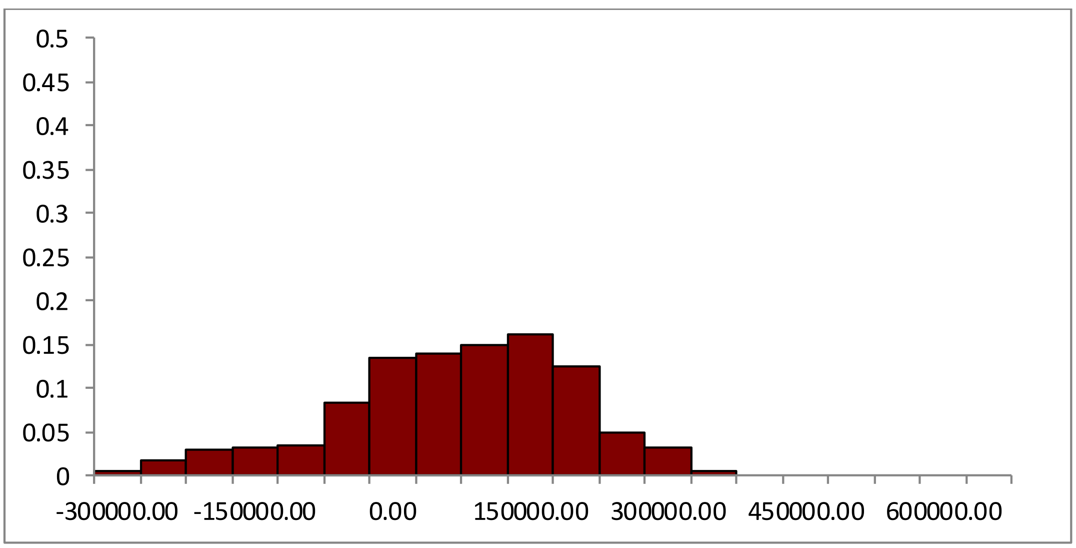

Figure 61: Profit for Cropping System D Logan County, Baseline 1

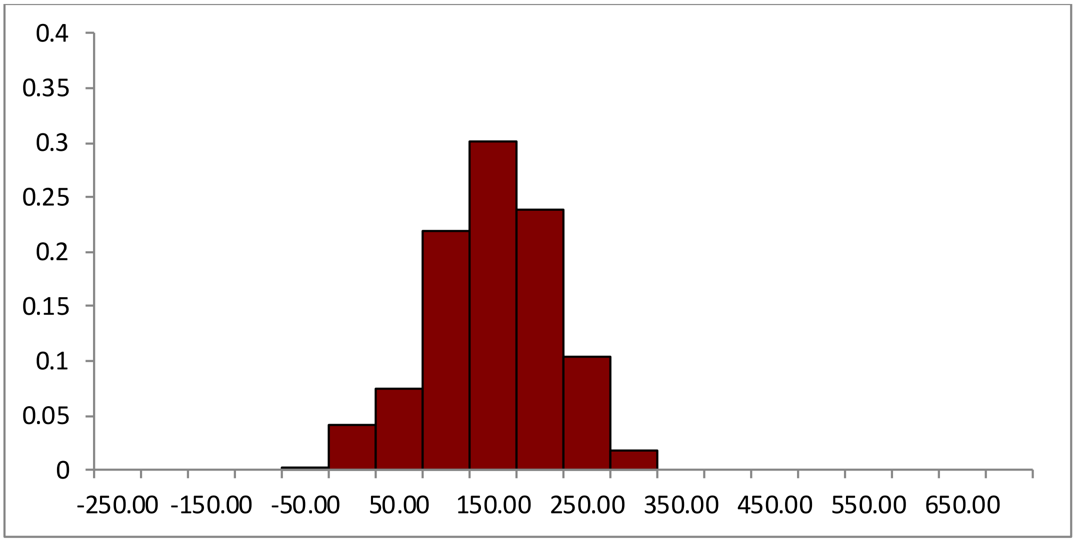

Figure 62: $/Acre Potentially Forgone Profits Cropping System A Logan County Baseline 1

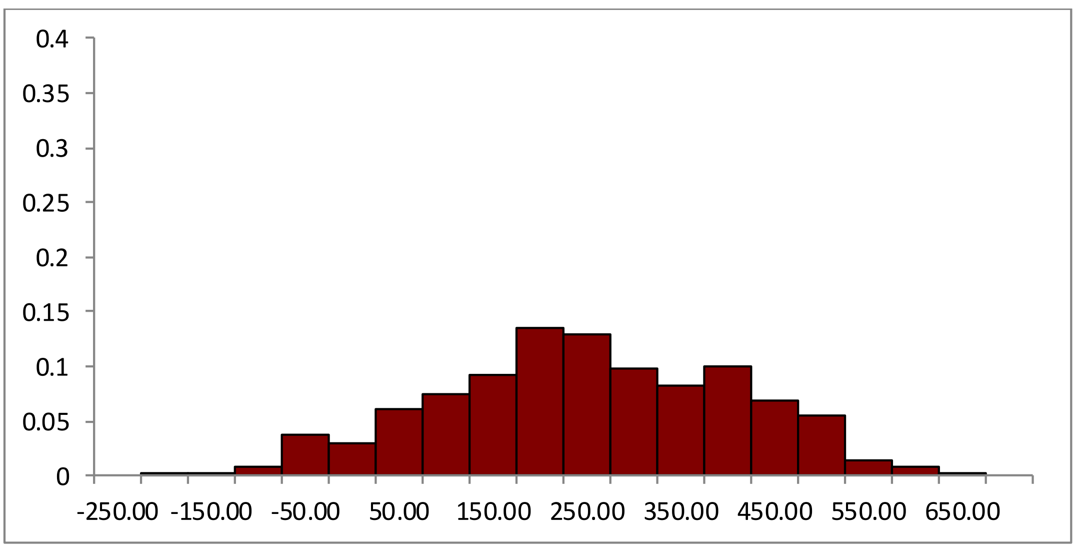

Figure 63: $/Acre Potentially Forgone Profits Cropping System B Logan County Baseline 1

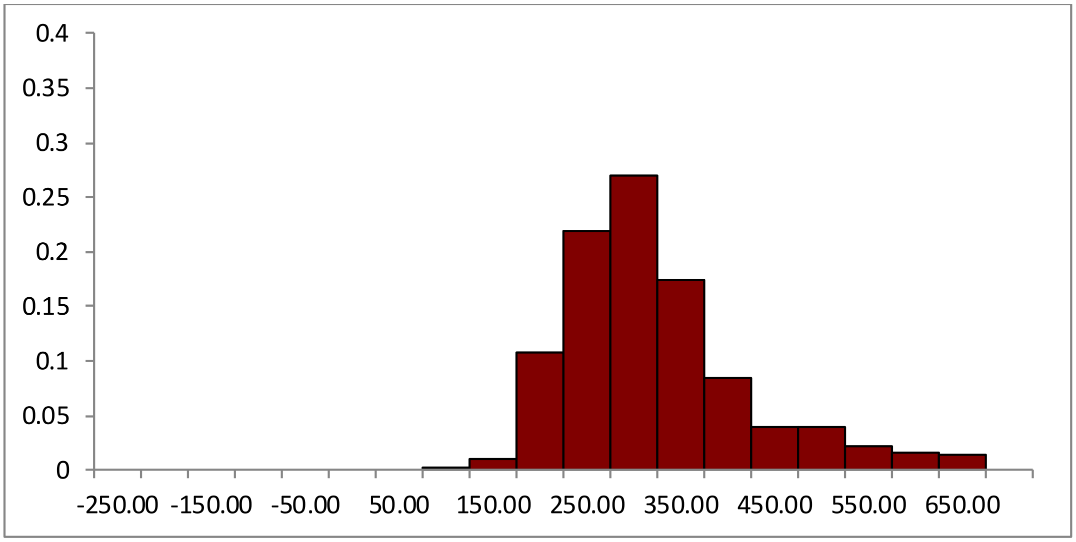

Figure 64: $/Acre Potentially Forgone Profits Cropping System C Logan County Baseline 1

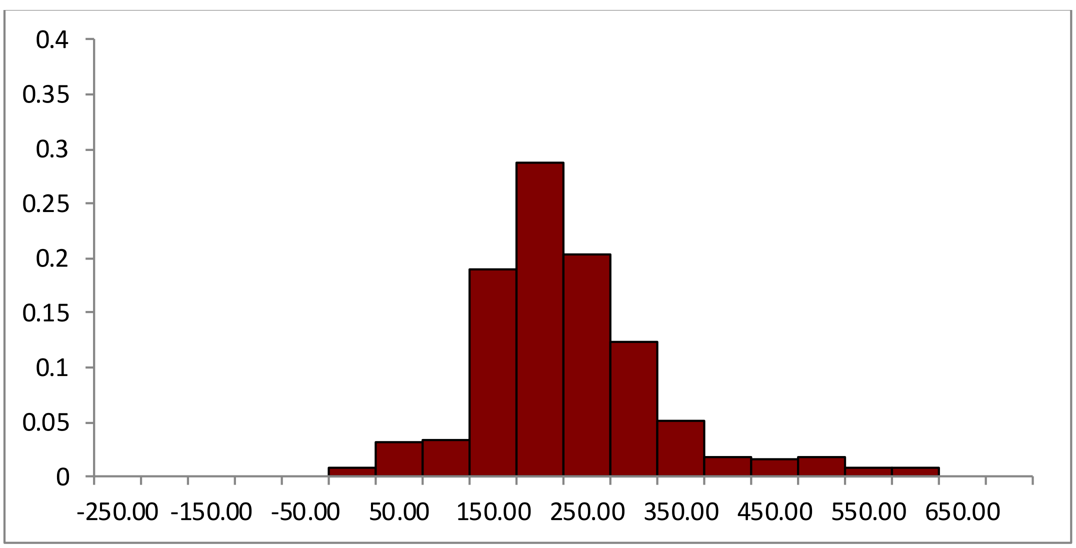

Figure 65: $/Acre Potentially Forgone Profits Cropping System D Logan County Baseline 1

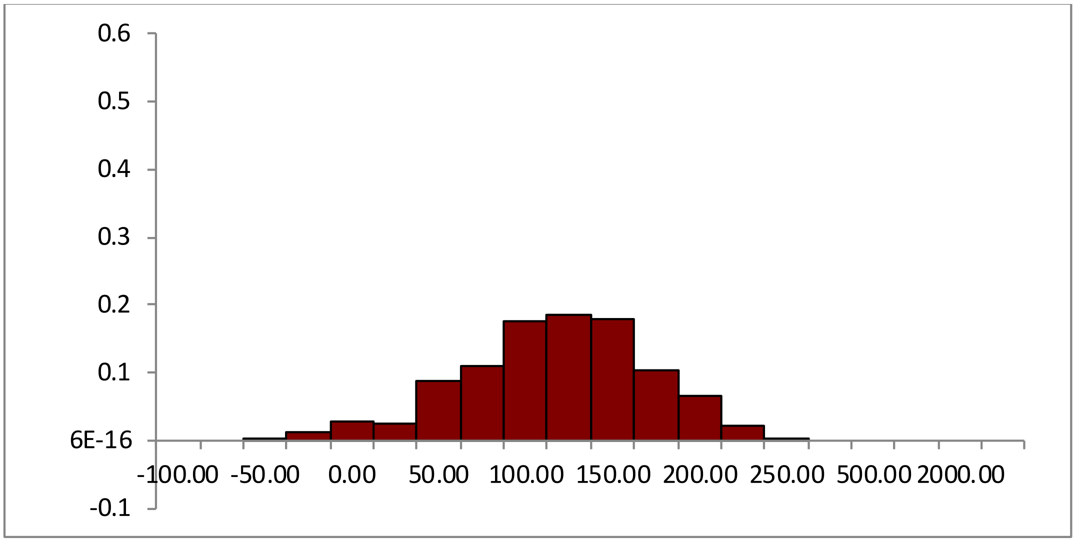

Figure 66: $/CU Potentially Forgone Profits Cropping System A Logan County Baseline 1

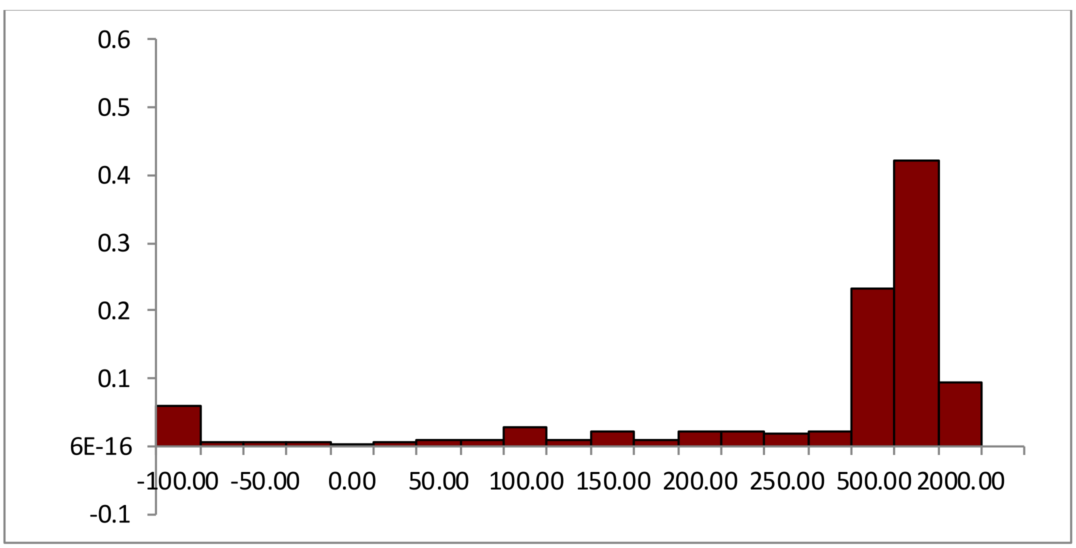

Figure 67: $/CU Potentially Forgone Profits Cropping System B Logan County Baseline 1

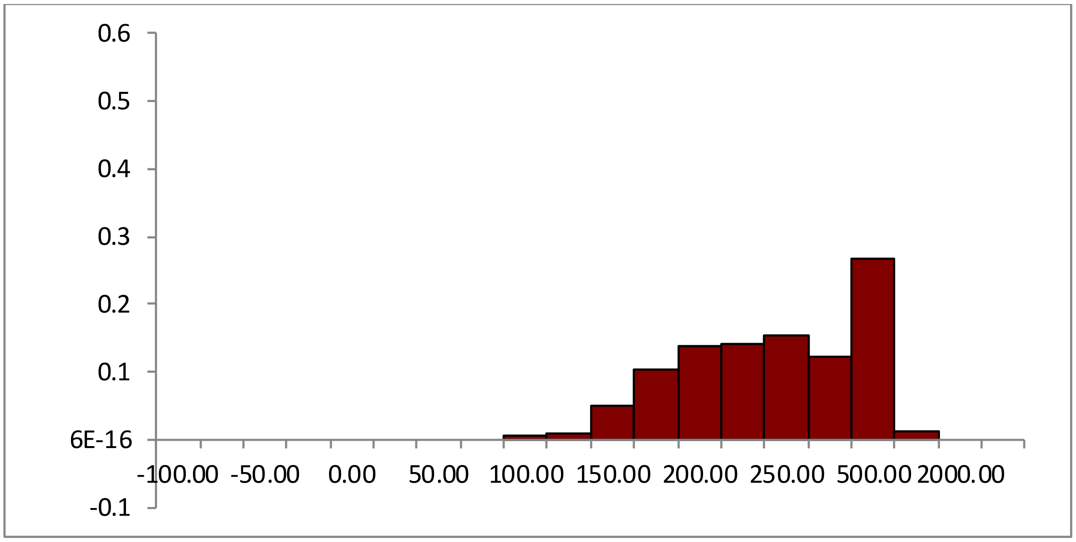

Figure 68: $/CU Potentially Forgone Profits Cropping System C Logan County Baseline 1

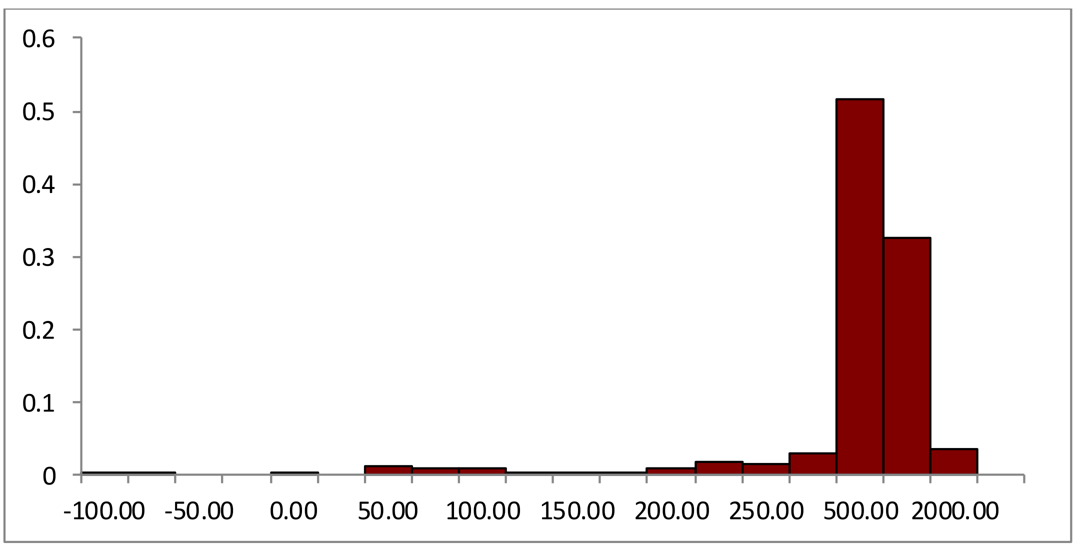

Figure 69: $/CU Potentially Forgone Profits Cropping System D Logan County Baseline 1

Table 31: Percent of Iterations of Profits under Various Parameters and No-Compensation for Water Removed from Production in Logan County, in relation to Baseline 2 Mean Profits

Logan County (Mean Profit = $ 250,483)	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Profit < Baseline1 Mean Profit	48.20%	82.73%	91.49%	97.68%	94.07%
Profit < 10 % below Baseline1 Mean Profit	39.95%	72.42%	89.95%	97.68%	93.04%
Profit < 20 % below Baseline1 Mean Profit	32.99%	63.40%	87.89%	97.68%	89.43%
Profit > Baseline1 Mean Profit	49.48%	14.95%	6.19%	0.00%	3.61%
Profit > 10 % above Baseline1 Mean Profit	42.78%	9.02%	4.64%	0.00%	0.77%
Profit > 20 % above Baseline1 Mean Profit	34.28%	5.41%	2.84%	0.00%	0.26%
Profit < 0	4.38%	4.38%	4.38%	61.08%	32.99%

Table 32: Percent of Iterations with $ 86 /CU Compensation Logan County *Baseline 1*

Percent of Iterations with $ 86 /CU Compensation Logan County *Baseline 1*					
Logan County Mean Profit = 250,483	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Profit < Baseline1 Mean Profit	48.20%	36.86%	87.63%	90.72%	84.28%
Profit < 10 % below Baseline1 Mean Profit	39.95%	26.55%	83.51%	84.28%	78.09%
Profit < 20 % below Baseline1 Mean Profit	32.99%	19.33%	77.32%	76.80%	69.33%
Profit > Baseline1 Mean Profit	49.48%	63.40%	12.63%	9.54%	15.98%
Profit > 10 % above Baseline1 Mean Profit	42.78%	52.06%	9.28%	5.15%	10.05%
Profit > 20 % above Baseline1 Mean Profit	34.28%	40.46%	7.47%	2.06%	5.15%
Profit < 0	4.38%	0.00%	1.03%	19.33%	13.14%

Table 33: Percent of Iterations with Mean Equivalence Payment Logan County *Baseline 1*

Percent of Iterations with Mean Equivalence Payment Logan County *Baseline 1*					
Logan County Mean Profit = 250,483	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Profit < Baseline1 Mean Profit	48.20%	32.47%	28.87%	36.86%	37.11%
Profit < 10 % below Baseline1 Mean Profit	39.95%	22.16%	17.78%	27.32%	30.41%
Profit < 20 % below Baseline1 Mean Profit	32.99%	15.72%	7.73%	21.91%	22.68%
Profit > Baseline1 Mean Profit	49.48%	65.21%	68.81%	60.82%	60.57%
Profit > 10 % above Baseline1 Mean Profit	42.78%	54.64%	48.45%	53.35%	55.41%
Profit > 20 % above Baseline1 Mean Profit	34.28%	44.07%	30.67%	44.85%	47.68%
Profit < 0	4.38%	0.00%	0.00%	2.32%	2.58%

Logan County: *Baseline 2*

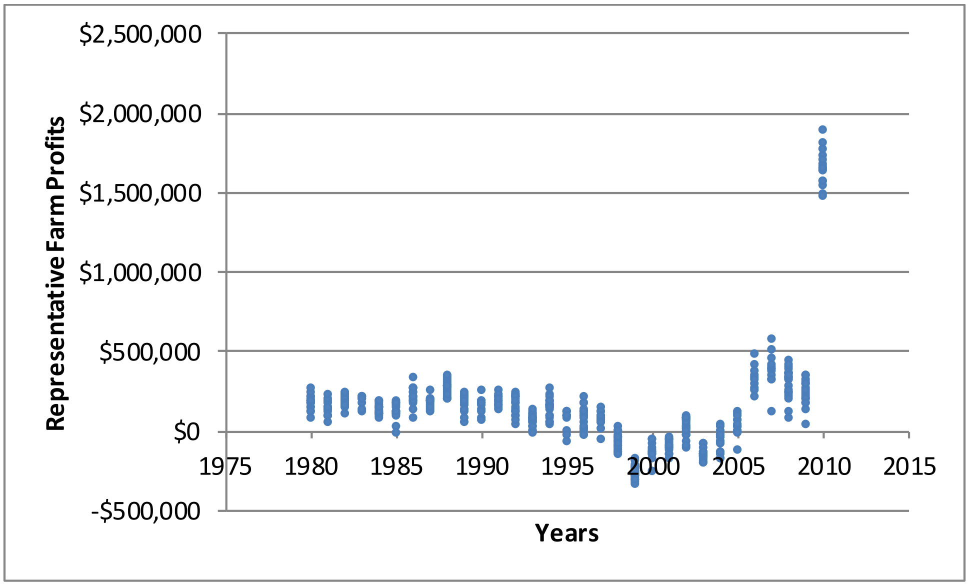

Figure 70: Simulation Results of Profits vs. Years for the Baseline 2 in Logan County

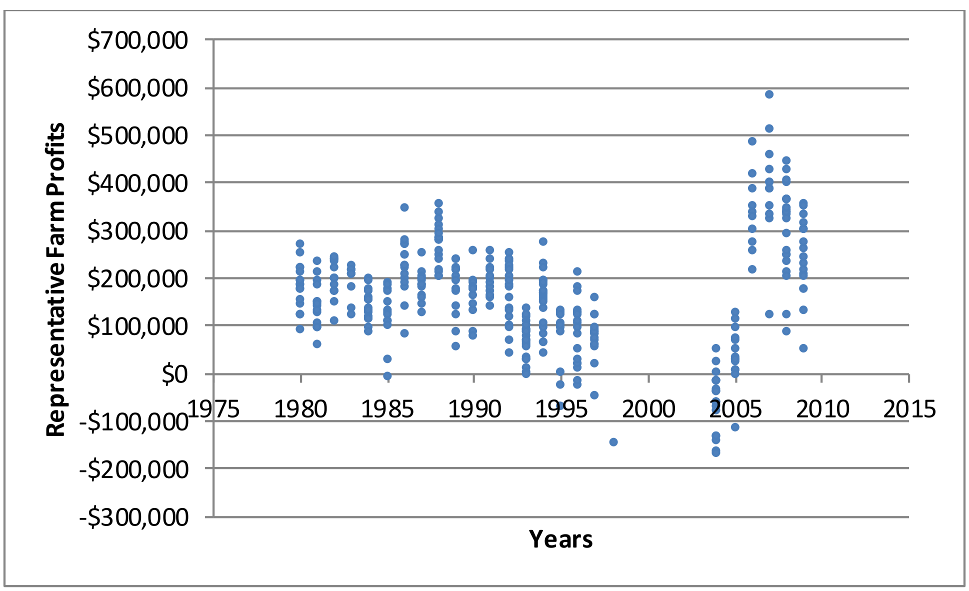

Figure 71: Adjusted Simulation Results of Profits vs. Years for the Baseline 2 in Logan

Table 34: Summary Statistics of Profits for a Representative Farms for Logan County Baseline 2 All Simulated Data

STATISTICS	***Baseline 1***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	155,841	144,233	83,638	-81,179	10,090
St. Dev.	316,596	232,759	204,420	281,576	280,093
COV	203	161	244	-347	2,776
Min	-325,372	-180,860	-251,314	-448,986	-446,028
Max	1,897,092	1,419,162	1,196,289	1,378,301	1,399,928

Table 35: Summary Statistics of Profits for a Representative Farm for Logan County Baseline 2 Adjusted Data

STATISTICS	***Baseline 2***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	165,644	151,136	89,984	-63,354	34,252
St. Dev.	114,917	87,371	83,425	134,723	142,527
COV	69	58	93	-213	416
Min	-166,094	-113,359	-150,955	-410,417	-330,116
Max	586,723	364,957	404,202	207,166	367,374

Table 36: Summary Statistics of Potentially Foregone Profits $/CU for a Representative Farm for Logan County Baseline 2 Adjusted Data

	Potentially Foregone Profits $/CU			
STATISTICS	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	11	95	134	138
St. Dev.	52	55	79	126
COV	465	58	59	92
Min	-104	-71	-2	-138
Max	176	229	359	536

Table 37: Summary Statistics of Potentially Foregone Profits $/Dry Acre for a Representative Farm for Logan County Baseline 2 Adjusted Data

	Potentially Foregone Profits $/Acre			
STATISTICS	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Mean	22	113	229	131
St. Dev.	101	66	135	121
COV	465	58	59	92
Min	-204	-85	-3	-132
Max	346	274	614	511

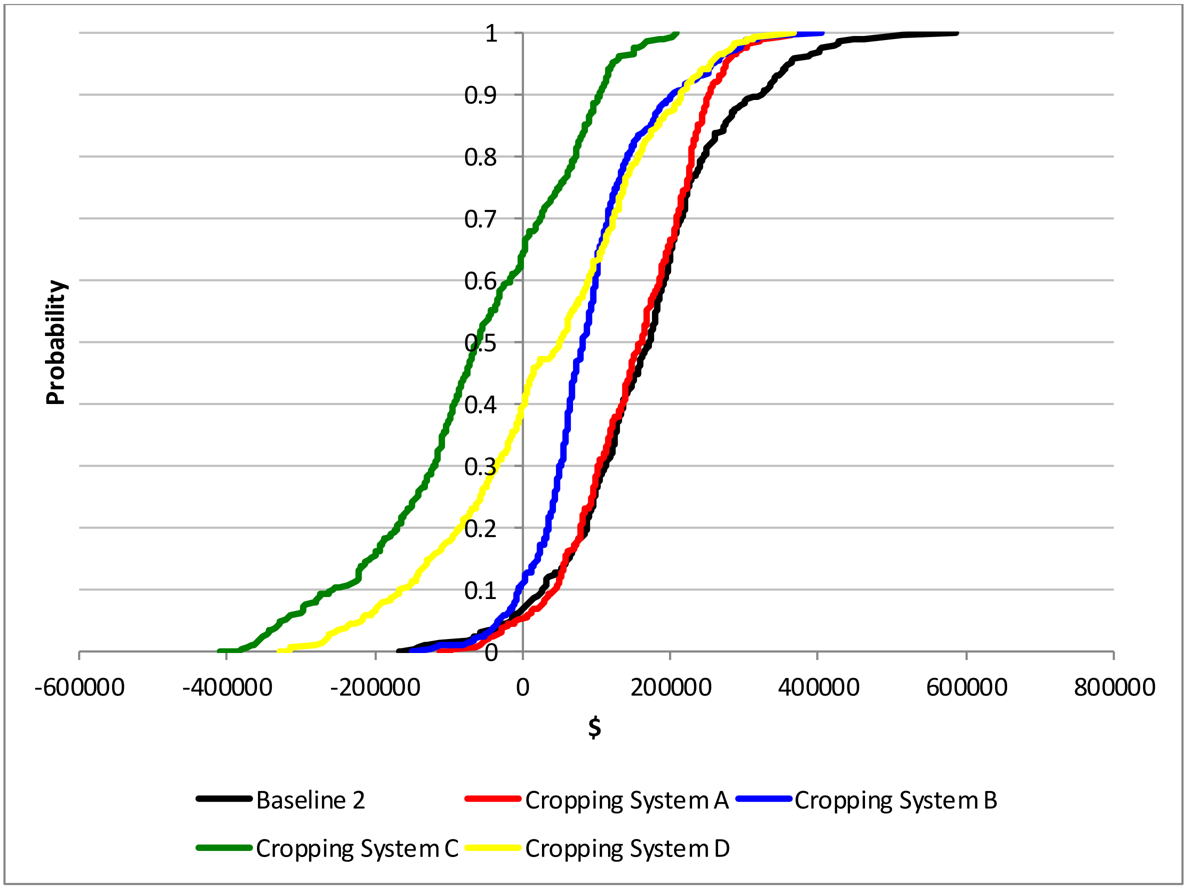

Figure 72: Cumulative Distribution Frequencies Logan County Baseline 2

Table 38: Important Values from the CDF for Logan County

LOGAN	***Baseline 2***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
50%	$171,443	$160,659	$80,387	-$60,613	$50,230
Profit < $0	7.00%	5.00%	11.00%	64.00%	40.00%
Profit > $250,000	18%	10%	6%	0%	6%

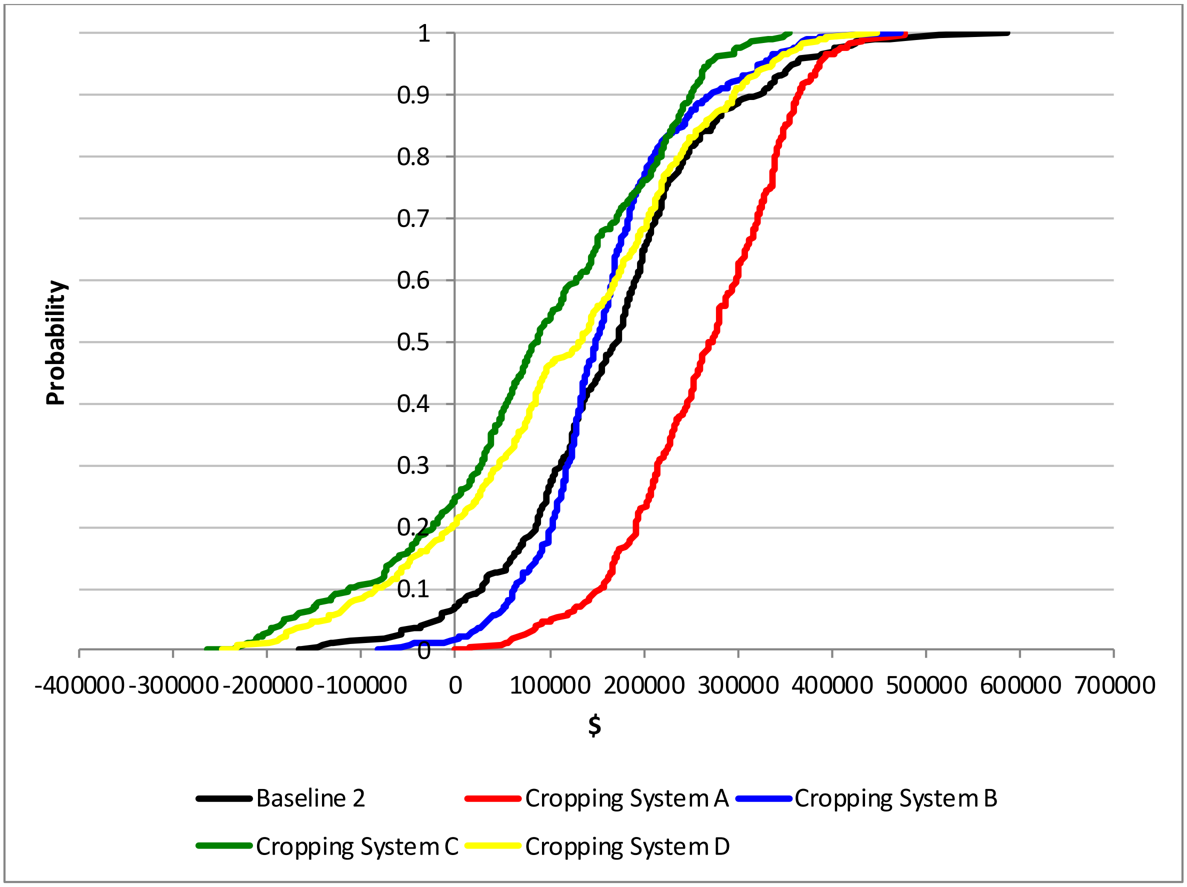

Figure 73: Baseline 2 and Alternative Cropping Systems with $28 / acre foot CU payment Logan County

Table 39: Important Value from CDF for Logan County with Payment

LOGAN (w/ $28)	***Baseline 2***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
50%	$171,443	$273,357	$149,079	$86,349	$132,262
Profit < $0	7.00%	0.00%	1.60%	24.70%	20.20%
Profit > $250,000	18%	60%	13%	10%	17%

Table 40: With and Without Payment Comparison

Baseline 2 LOGAN	Mean Total Profit ($)			
	Cropping System A	***Cropping System B***	***Cropping System C***	***Cropping System D***
w/out payment	$ 151,136	$ 89,984	$ -63,354	$ 34,252
w/ $ 28.00 payment	$ 187,824	$ 112,345	$ -15,510	$ 60,956

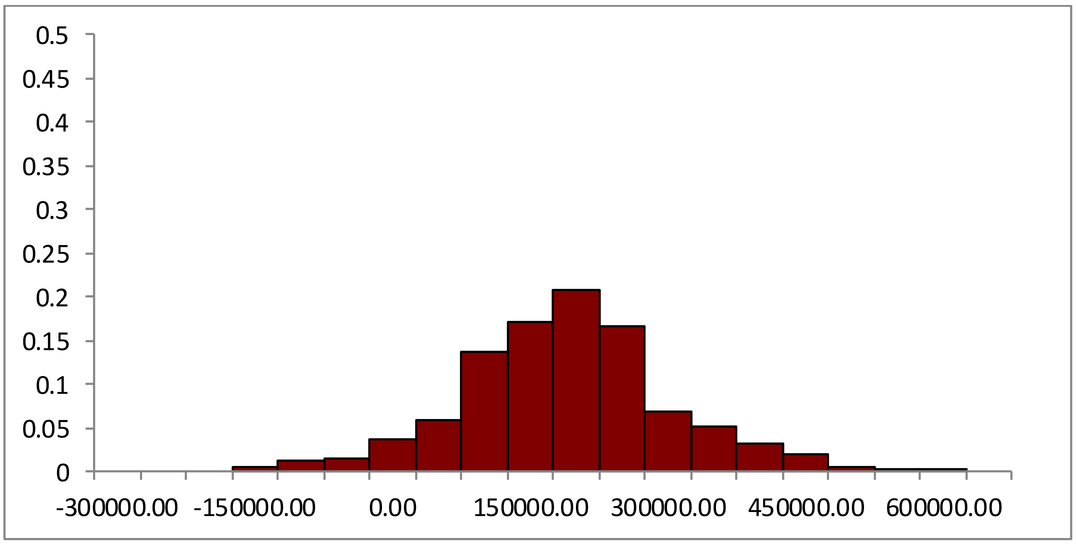

Figure 74: Profit Baseline 2 Logan County

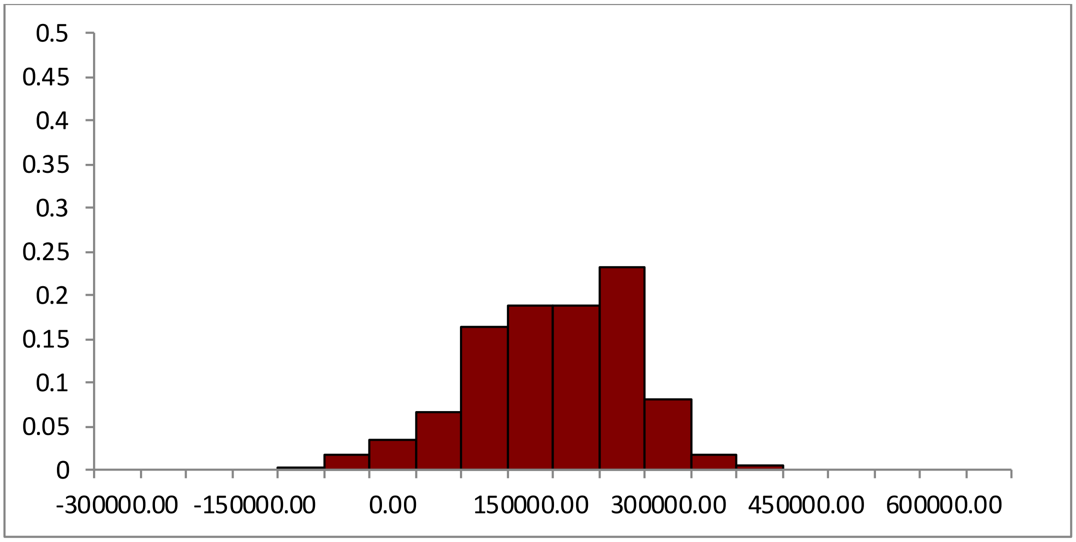

Figure 75: Profit Cropping System A Logan County Baseline 2

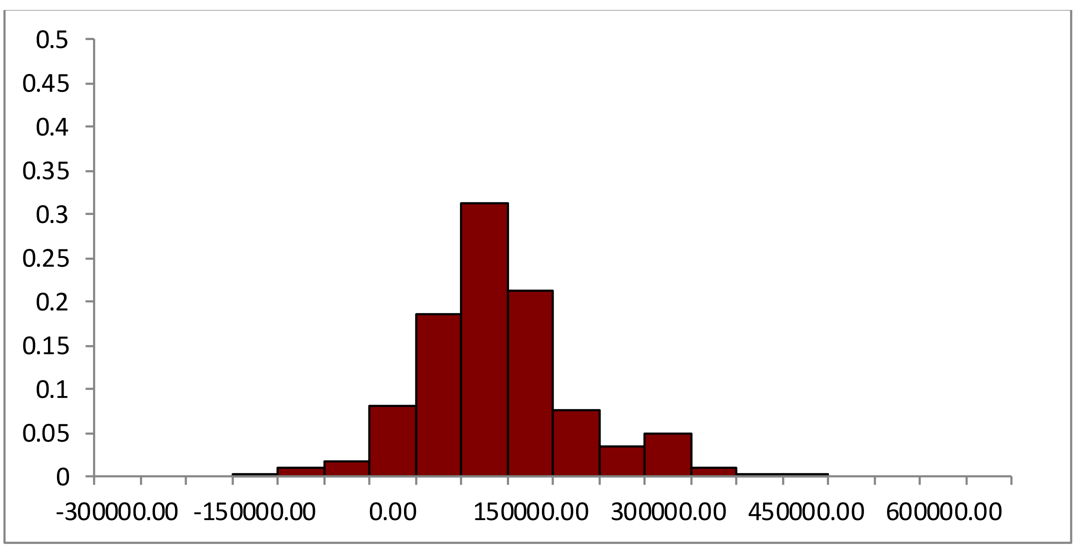

Figure 76: Profit Cropping System B Logan County Baseline 2

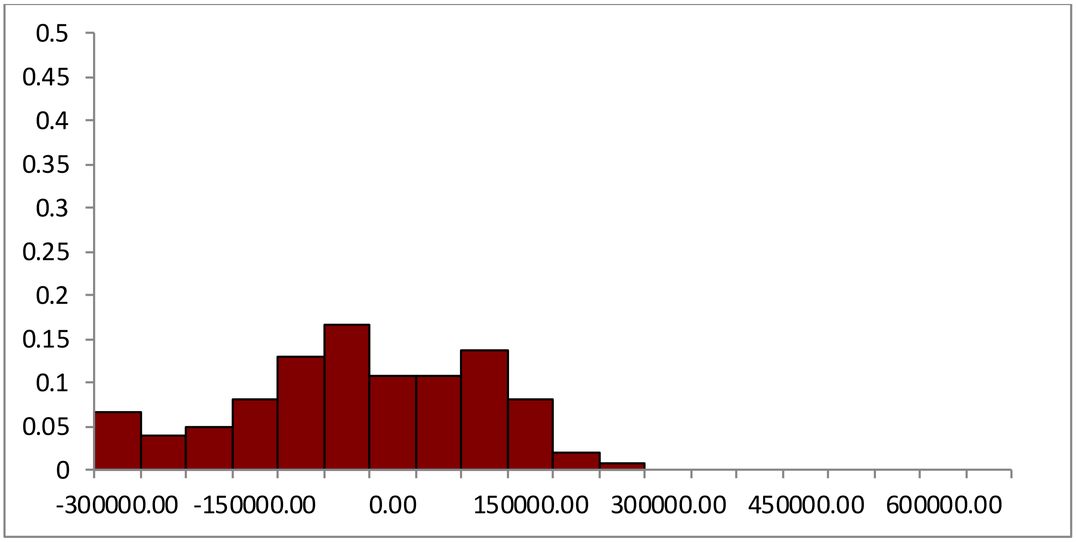

Figure 77: Profit Cropping System C Logan County Baseline 2

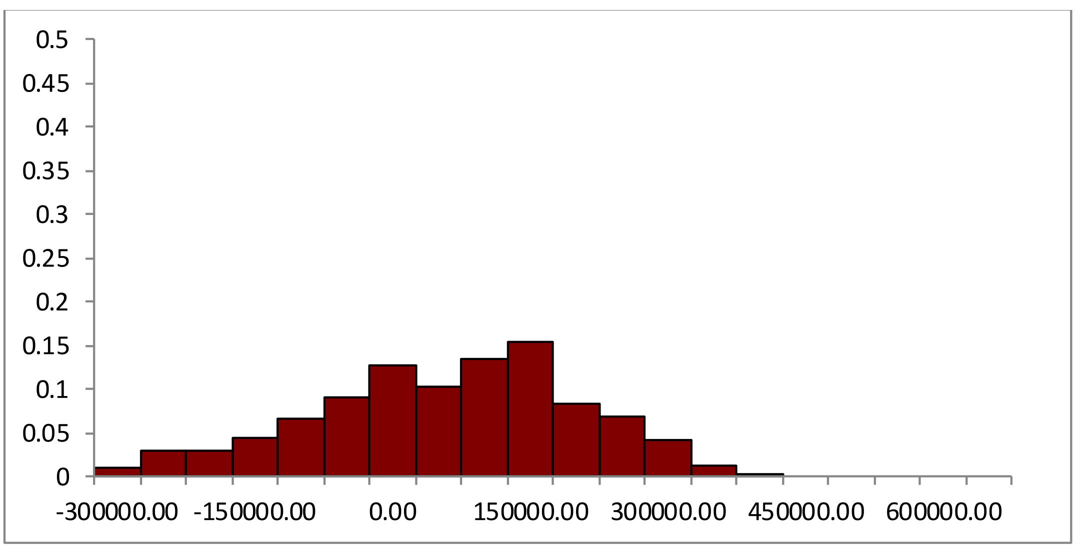

Figure 78: Profit Cropping System D Logan County Baseline 2

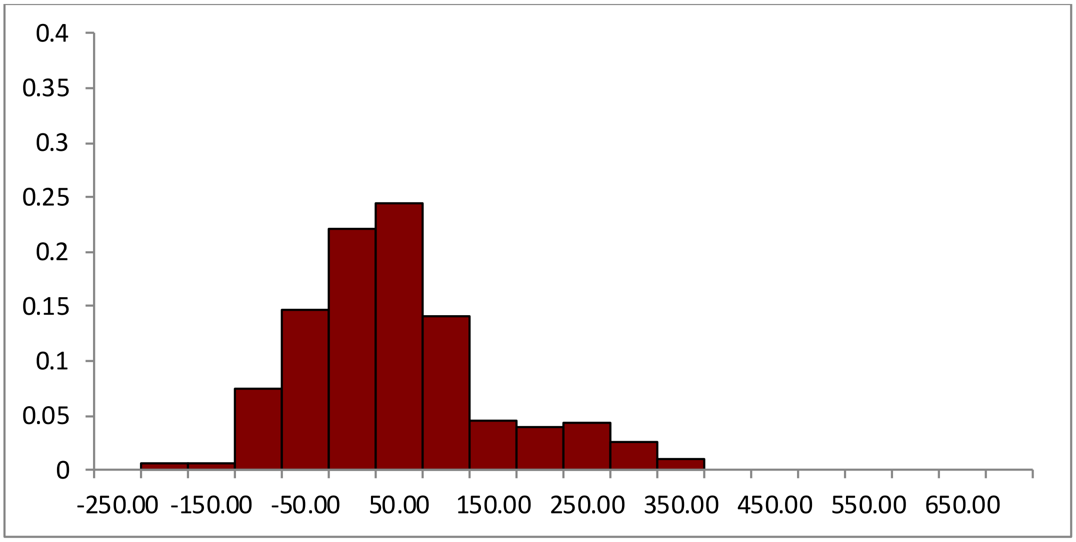

Figure 79: $/Acre Potentially Forgone Profits Cropping System A Logan County Baseline 2

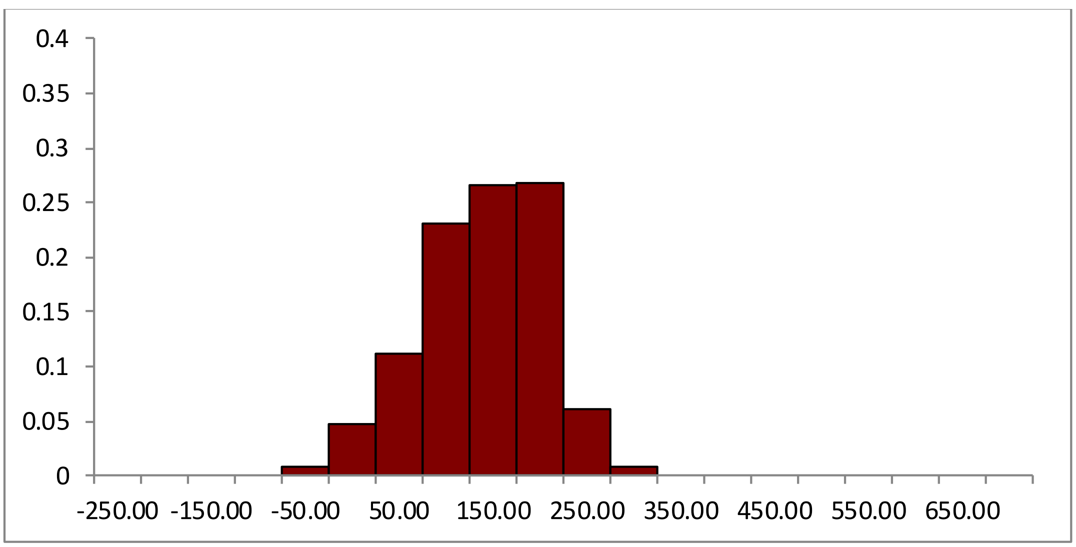

Figure 80: $/Acre Potentially Forgone Profits Cropping System B Logan County Baseline 2

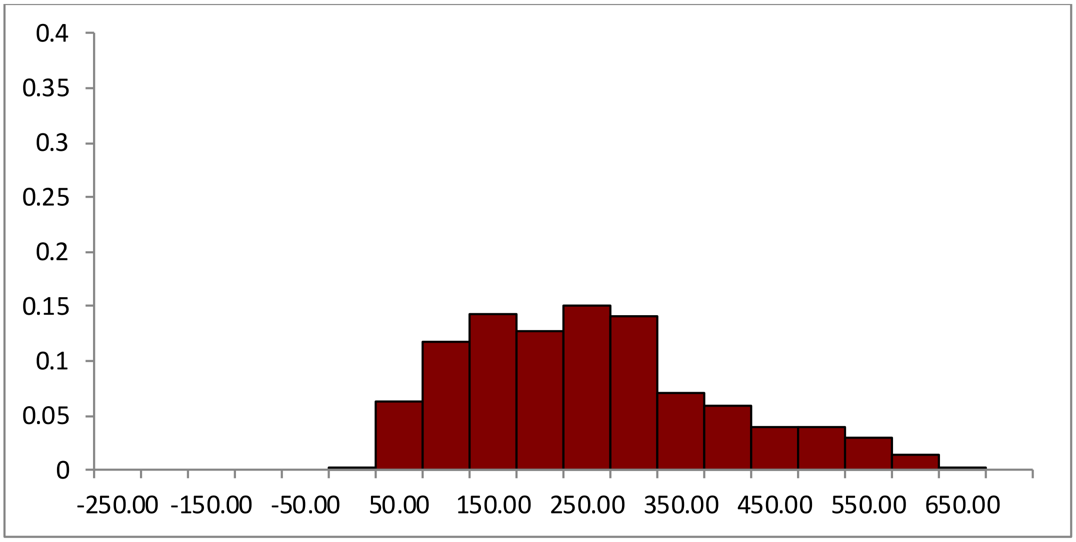

Figure 81: $/Acre Potentially Forgone Profits Cropping System C Logan County Baseline 2

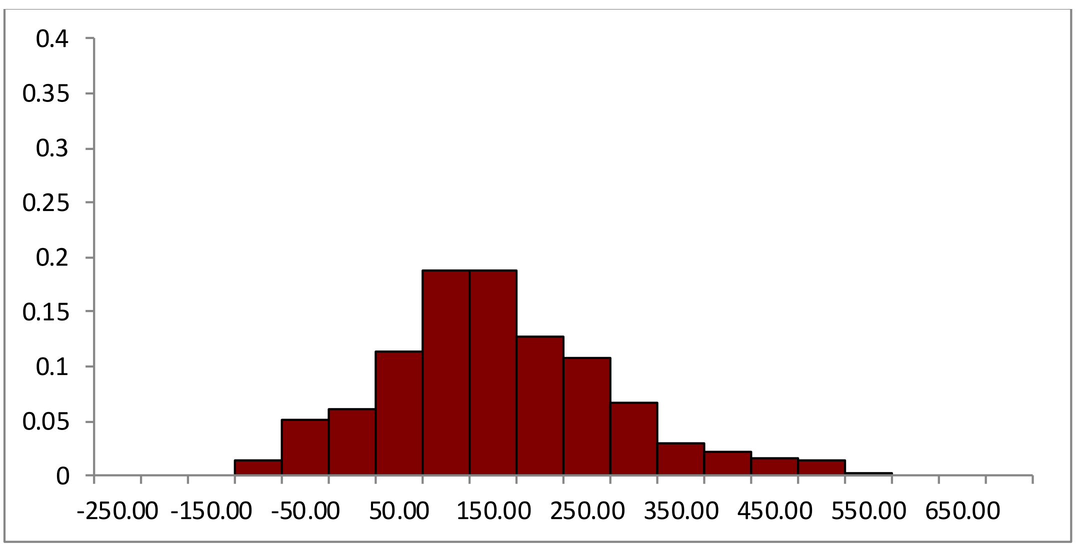

Figure 82: $/Acre Potentially Forgone Profits Cropping System D Logan County Baseline 2

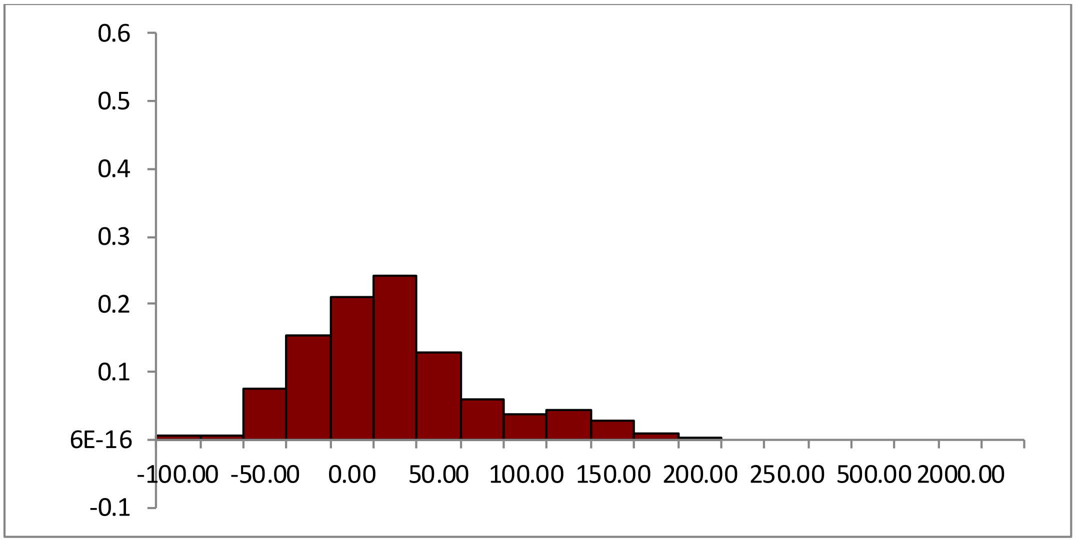

Figure 83: $/CU Potentially Forgone Profits Cropping System A Logan County Baseline 2

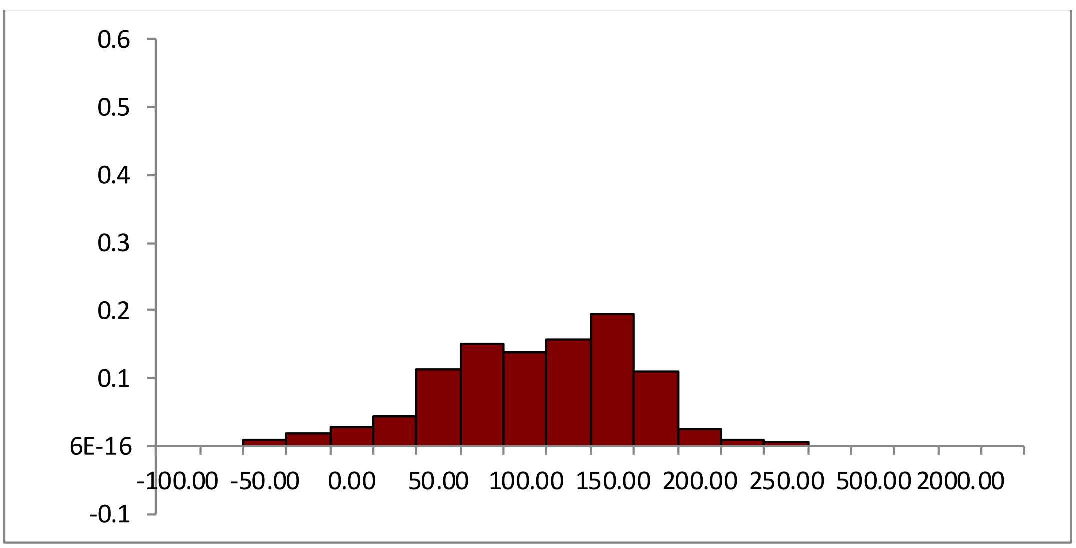

Figure 84: $/CU Potentially Forgone Profits Cropping System B Logan County Baseline 2

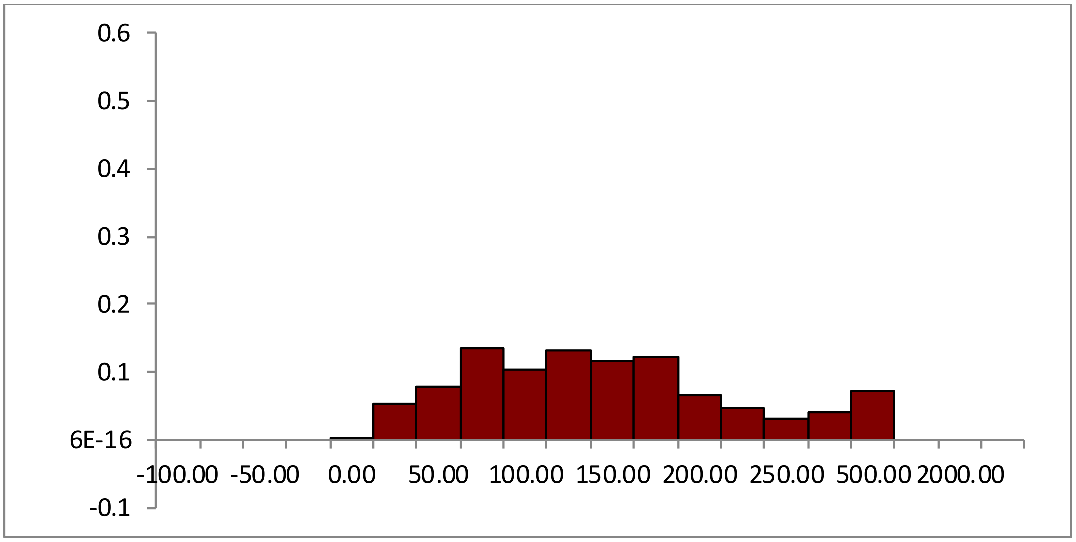

Figure 85: $/CU Potentially Forgone Profits Cropping System C Logan County Baseline 2

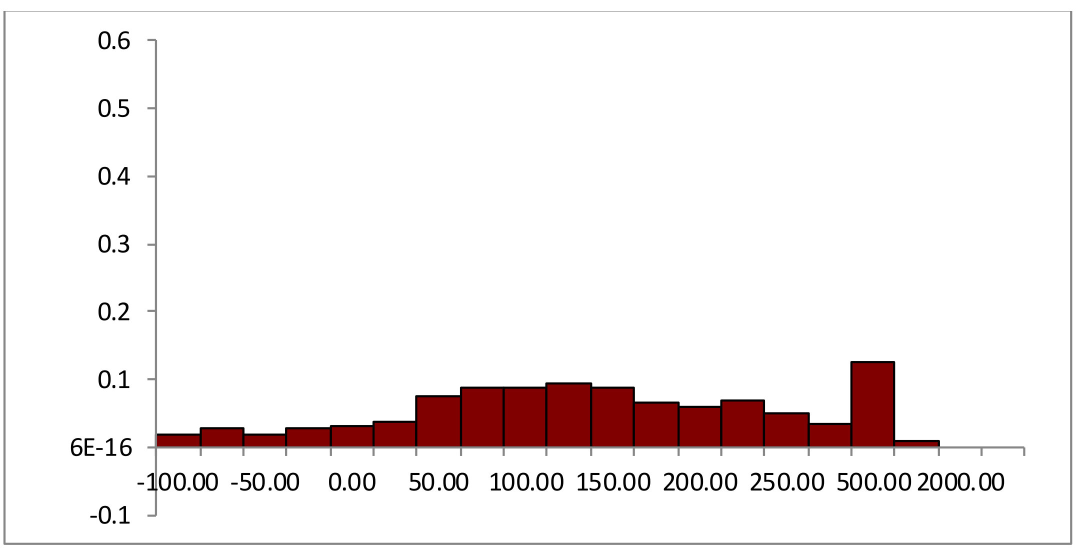

Figure 86: $/CU Potentially Forgone Profits Cropping System D Logan County Baseline 2

Table 41: Number of Iterations of Profits under Various Parameters and No-Compensation for Water Removed from Production in Logan County, in relation to Baseline 2 Mean Profits

LOGAN County (Mean Profit = $165,644)	***Baseline 2***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Profit < Baseline2 Mean Profit	47.68%	51.29%	82.22%	95.88%	80.41%
Profit < 10 % below Baseline2 Mean Profit	42.78%	46.13%	80.15%	94.07%	77.06%
Profit < 20 % below Baseline2 Mean Profit	38.14%	38.66%	75.00%	94.07%	71.91%
Profit > Baseline2 Mean Profit	50.00%	46.39%	15.46%	1.80%	17.27%
Profit > 10 % above Baseline2 Mean Profit	43.04%	39.95%	12.11%	1.29%	14.43%
Profit > 20 % above Baseline2 Mean Profit	34.79%	33.51%	10.31%	0.77%	12.37%
Profit < 0	6.96%	5.41%	11.08%	62.63%	38.66%

Table 42: Frequency of Iterations with Mean Equivalence Payment Logan County Baseline 2

Frequency of Iterations with Mean Equivalence Payment Logan County *Baseline 2*					
Logan County *Baseline 2* Mean = 165,644	***Baseline 2***	***Cropping System A***	***Cropping System B***	***Cropping System C***	***Cropping System D***
Profit < Baseline2 Mean Profit	47.68%	37.37%	39.95%	39.69%	42.53%
Profit < 10 % below Baseline2 Mean Profit	42.78%	31.19%	27.84%	34.54%	35.82%
Profit < 20 % below Baseline2 Mean Profit	38.14%	24.23%	18.81%	28.87%	31.44%
Profit > Baseline2 Mean Profit	50.00%	60.31%	57.73%	57.99%	55.15%
Profit > 10 % above Baseline2 Mean Profit	43.04%	54.38%	48.20%	52.32%	51.29%
Profit > 20 % above Baseline2 Mean Profit	34.79%	48.71%	39.95%	39.95%	50.00%
Profit < 0	6.96%	2.58%	1.29%	10.31%	10.31%