STOCHASTIC BUDGETING AND INPUT BREAKEVEN ANALYSIS IN NORTH DAKOTA POTATO PRODUCTION

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Enterprise budgets were developed for non-irrigated red and irrigated russet potato production, based on North Dakota model farms. Costs and revenues vary among producers, thus budgets are intended to serve as a template for producers to use and manipulate to suit their individual circumstances. These budgets and stochastic (Monte Carlo) simulation were utilized in order to analyze and quantify financial risk in each respective enterprise. Simulated net returns for non-irrigated production ranged from -$1,324 to $2,757 per acre, while irrigated returns were between -$551 and $1,616 per acre. On farms where fumigation is a typical practice, it is one of the largest expenses to the enterprise. A break-even analysis was conducted based on market price and possible increases in yield and yield quality. The breakeven curve is downward sloping, as market price increases. Ideal product selection, based on assumed benefits, may vary depending on expected market price.

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DEDICATION

To my beautiful bride Diane, for her continued support, encouragement, and confidence in me; and to my three wonderful little girls who are some of my greatest cheerleaders without even realizing it. And to my parents who instilled in me, from a young age, a desire to pursue higher education.

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INTRODUCTION

The United States potato industry produced over 44 billion pounds of potatoes in 2015, on just over one million acres of farm land (2016 Potato Statistical Yearbook). In that same year, Americans consumed 113.8 pounds of potatoes per capita. Approximately 30% of total consumption were fresh potatoes, 42% were frozen potato products such as French fries and hash browns, 18% were chips and shoestrings, and about 10% were dehydrated (2016 Potato Statistical Yearbook). Annual per capita consumption has been declining in the United States since the early 2000s, but increased in 2015 above 2014 and 2013 levels. Potatoes are a $3.8 billion industry in the United States (2016 Potato Statistical Yearbook).

North Dakota is the fourth largest potato producing state in the United States. In 2015, 2.7 billion pounds of potatoes were grown in the state, with a farm gate value of more than $258 million (2016 Potato Statistical Yearbook). Potatoes are an important part of agriculture and the economy in North Dakota. As a generalization, there are two types of production systems in ND, non-irrigated and irrigated. The majority of the potatoes grown for the fresh market in ND are non-irrigated red-skinned potatoes. The Red River Valley of North Dakota and Minnesota is the largest red potato growing region in the country (NPPGA, 2017). Some of the common red-skinned cultivars grown are Red Norland, Dark Red Norland, Red LaSoda, and Viking. Most of the potatoes grown outside of the Red River Valley are irrigated and grown for French fry processing (NPPGA, 2017). Some of the common cultivars grown for processing are Russet Burbank, Ranger Russet, Umatilla Russet, and Bannock Russet.

Potatoes are a high input crop, they are susceptible to a wide range of pests and diseases, and require frequent pesticide applications. They require specialized field and handling equipment. To maximize quality, potatoes should be stored in climate controlled storages. They are perishable and have a high water content, making the raw product expensive to transport long distances. Inputs and production practices vary considerably among potato producing regions of the country due to climate, regional pest and disease presence, access to human, capital, and natural resources; and the intended market use of the product. There are also significant differences between irrigated and non-irrigated systems. The cost of production for a non-irrigated red grower in North Dakota will look quite different from the irrigated russet grower in the same region because the red grower has lower input costs and a shorter growing season from planting to maturity. There will also be differences among operations due to efficiency and economies of scale. In other words, a larger operation will often be able to utilize resources more efficiently by being able to spread costs over a greater volume of output, or secure lower input prices through bulk purchasing. Cost and revenue may also vary due to diversity in contracts, marketing, and individual agreements with suppliers. Due to these and other factors, it is difficult to estimate a budget that is widely applicable with relative accuracy. Budgets based on regional inputs and a clear set of assumptions that individual potato growers can manipulate to suit their needs and reflect their own constraints and circumstances are needed.

Deterministic enterprise budgets are often made to project an expectation of the financial revenues and costs for the coming year; however, in reality it only represents one snapshot of many possible outcomes for the farm. Some elements of a budget are fairly predictable and can be planned for with some degree of certainty, while others may be quite variable, unpredictable, and outside the realm of control of the potato grower. This fact makes potato production, and most other agricultural enterprises, financially risky to engage in. Risk is a term often used to describe elements of potato production, but it is not often spoken of in such a way as to understand how much is actually at stake, or how one decision may be more or less risky than another. Stochastic budgeting provides a method to quantify the level of risk by simulating many possible outcomes, based on the statistical distributions of possible values for highly variable budget items. Several researchers advocate the use of stochastic budgeting as a tool for the analysis of risk. Lien (2003) demonstrated the usefulness of stochastic budgeting to evaluate production decisions on a Norwegian dairy farm. Grove et al. (2007) employed stochastic budgeting as a tool for the analysis of conversion from beef farming to game ranching in South Africa.

One budget item of particular importance to potato production, due to the high cost associated with it, is fumigation. Fumigation accounts for approximately 17% of total operating costs in the ND model farm budget for irrigated russet potatoes. Many growers have adopted the practice of fumigating their potato fields in order to protect their potato plants from a number of yield limiting diseases and pests; however, some growers may be hesitant to adopt the practice because of the high cost. Soil fumigation is thought to improve both total yield and quality, but the question is whether the benefits gained are enough to offset the cost incurred.

Objectives

North Dakota State University does not currently have published enterprise budgets for potatoes produced under non-irrigated or irrigated conditions. The first objective of this study was to create enterprise budgets for both non-irrigated red potato production and irrigated russet potato production based on a representative model farm. The second objective of this study was to employ the enterprise budgets and stochastic simulation to quantify and analyze the risk of non-irrigated red potato production and irrigated russet potato production. The third objective of this study was to provide a framework that could be used by producers as a guideline to conduct a breakeven analysis of fumigation in their own operation, based on expected changes in yield, quality, and potato prices.

The remainder of this thesis is organized as follows. Chapter 1 (Non-Irrigated Red Potato Production and Risk) discusses the development of the enterprise budget and risk evaluation through stochastic simulation for non-irrigated red potato production. Chapter 2 (Irrigated Russet Potato Production and Risk) discusses the irrigated russet potato budget and the stochastic evaluation of risk in that enterprise. Chapter 3 (Fumigation Cost and Break-Even Analysis) is a breakeven analysis of fumigation based on potato price and yield increases and improvements.

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NON-IRRIGATED RED POTATO PRODUCTION AND RISK

Abstract

It is commonly accepted that potato production is a high risk enterprise. Quantifying this risk can increase understanding so that producers may rank the relative risk of potato production against the risk of other opportunities. Currently, there is not a published enterprise budget for non-irrigated red potato production in North Dakota. An enterprise budget was first developed based on a representative model farm in the Red River Valley. Distributions were derived for the budget to represent ranges for possible price by tuber size and total yield. These distributions were sampled randomly in a Monte Carlo simulation with 5,000 iterations, to derive a range of possible net returns, in order to quantify the risk the enterprise is exposed to. The mean net return was $205 per acre with a standard deviation of $638 per acre. Simulated net returns were widely spread from a loss of $1324, to a gain of $2757 per acre. Non-irrigated potato production is a risky enterprise.

Introduction

The Red River Valley of North Dakota and Minnesota is the largest red potato growing region in the United States, with these two states producing nearly 40% of all red potatoes grown in the US (National Potato Council, 2016). Approximately 64% of the potato acreage grown in North Dakota is grown under non-irrigated conditions (USDA, 2016). Non-irrigated potato farms in the state primarily produce red potatoes for the fresh market (NPPGA, 2017). Potatoes are a high input crop requiring frequent chemical treatments, specialized equipment, expensive climate controlled storages, and careful handling to preserve quality. An enterprise budget is an important financial tool for producers to use in planning for these challenges.

Enterprise budgets provide a summary of all revenues and costs related to the enterprise for a given financial period, usually one year for agricultural enterprises. They are not a reflection of the entire farm. The cost of resources that are shared across multiple enterprises on the farm, such as tractors or tillage implements, are allocated proportionally, according to their use in each enterprise. In addition to a whole farm budget, an enterprise budget is important because it allows a producer to analyze the performance of each operation independently of others on the farm. Crop enterprise budgets have been published for irrigated potatoes in other states (Patterson, 2013; Galinato and Tozer, 2016; Bogash et al. 2013), but little work has been done on developing an enterprise budget for non-irrigated red potato production in North Dakota or elsewhere.

Although a traditional enterprise budget is a valuable tool, its utility for risk management is somewhat limited, in that it only represents a single, fixed scenario; however, it provides a starting point for additional analysis. There are a number of unpredictable and uncontrollable factors causing variability and risk within the budget. It is often said that potato production is a "high risk, high reward" business, but what does that actually mean? It is true that there is a high level of risk involved in commercial potato production due to high input costs, variable yields, and volatile markets. The recent reduction in overall commodity prices has heightened the awareness of maintaining sustainable profit margins and managing risk. However, in order to accomplish this, it is important first to define what risk is in the context of an agricultural enterprise.

There is much discussion on the subject of risk in economics and there is not a single accepted definition of the term. The terms risk and uncertainty are often used interchangeably to describe a situation where the outcome is unknown; however, Knight (1921), and subsequent researchers, suggested a distinction between these two terms based upon information available from similar past situations. Knight proposed that if a decision maker faced a choice with multiple possible outcomes, which was similar to something that had occurred in the past, from which a probability density could be generated, the decision maker faced a risky decision. Additionally, uncertainty was represented when a decision maker faced a unique situation with no precedent and multiple possible outcomes (Knight 1921). Knightian risk is measurable, while uncertainty is immeasurable, and thus impossible to calculate. Risky decisions, events, or outcomes can be graded as more risky or less risky than another, while uncertain events cannot.

Robinson and Barry (1987) pointed out that decision makers must often make probability judgments with little or no empirical support or precedent. These would be situations that Knight would consider uncertain; however, once the judgment has been made by the decision maker, the decision making process is nearly the same, whether facing risk or uncertainty (Robinson and Barry 1987). For this reason, many economists do not maintain the distinction between risk and uncertainty, and often use the terms interchangeably. Robinson and Barry (1987) go on to propose the importance of distinguishing between the two terms. “[They] define as risky, those uncertain events whose outcomes alter the decision maker’s well-being” (Robinson and Barry 1987). This is different than the definition proposed by Knight (1921) and others where the two terms are mutually exclusive. Instead, based on Robinson and Barry’s (1987) definition, risky events are a subset of uncertain events, with uncertain events being those whose outcome is not known with certainty.

Agricultural producers are subject to a high degree of risk due to many factors, such as the biological nature of the production process, short run inelastic supply and demand, and variances of weather (Myers et al. 2010). In order to be successful in agricultural markets, it is important for producers to understand risk, and in what ways and to what degree their enterprise or business is exposed. Even with identical information, sometimes individual producers make decisions different from one another, under similar circumstances. This is due to differences in risk preferences among producers and the probability they assign to future events (Kazmierczak and Soto 2001). It is important for a producer to understand his or her individual risk preferences. Risk preferences are based on the level of risk aversion felt by an individual, and varies from person to person. Some of the factors that influence risk aversion are age, wealth, income, and education (Riley and Chow, 1992). There must be some means of quantifying risk in a manner that producers may rank potential “risky” decisions from least risky to most risky, so that they might make an informed decision based on their individual risk preferences.

One method for analyzing risky decisions is through the use of Monte Carlo simulation, also known as stochastic simulation. “Monte Carlo simulation encompasses any technique of statistical sampling employed to approximate solutions to quantify problems” (Kwak and Ingall 2007). Stochastic (or Monte Carlo) budgeting is a means by which that variability can be accounted for. Net returns can be calculated as a range of possibilities, and their probability of occurrence, rather than simply as a deterministic value. In this type of simulation, a model representing a real-life situation is developed with certain “risky” variables as inputs. Those variables are each defined by specified distributions of possible values. Distributions can have a number of shapes such as normal, beta, triangle, uniform, and others. Values are drawn at random from the distribution and inputted into the model, simulating the entire system a large number of times, or iterations. Each iteration represents a possible outcome for the model. The range of outputs, across all iterations can then be compiled into a distribution, to indicate not only what may happen, but also how likely it is to happen, based on the probabilities assigned to the inputs. This provides a metric with which to rank potentially “risky” decisions, from least risky to most risky, relative to one another. Kazmieczak and Soto (2001) utilized stochastic budgeting to compare riskiness of returns to various sizes of channel catfish production operations in the Mississippi Delta. Monte Carlo simulation can be a very powerful tool in trying to understand the potential effects of uncertainty and risk, but it is only as good as the model it is simulating and the information that is fed into it (Kwak and Ingall 2007). It is of the utmost importance to use the best data and other information available when fitting distributions from which to sample from.

Stochastic simulations begin with a fixed or deterministic model. Once the deterministic model is developed, simulation can begin by identifying risky variables and replacing their fixed values with stochastic distributions. Potato growers are exposed to risk from a myriad of sources. Weather is capricious; potatoes are a susceptible host to a variety of insects and harmful diseases; there are wide and unpredictable market fluctuations; consumer perceptions and unfavorable public policy can drive market declines; input costs are high and may vary without respect to potato price; and markets can shift due to changes in technology and consumer preferences. Within the construct of an enterprise budget, many of the most impactful risks faced by producers could be represented directly or indirectly in yield and price received.

The first objective of this study was to develop a deterministic enterprise budget for non-irrigated red potatoes produced for the fresh market, based on local input costs and constraints faced by a representative model farm of a size and scale typical to the Red River Valley. The second objective was to utilize the deterministic enterprise budget to build a stochastic budget with which to simulate and quantify the level of risk involved in non-irrigated red potato production.

Materials and Methods

Model Farm

In order to estimate the cost of production for non-irrigated red potatoes, a model farm was created. This was not intended to represent any one grower, but to be a representative 2,000 acre farm in the Red River Valley of North Dakota. The soil type was a clay loam with a normal seasonal (May through August) rainfall of 12.1 inches (NDAWN, 2017). The crop rotation is potato, followed by sugarbeet, dry bean, and wheat for one year each. The farm was designed to grow 500 acres of each crop each year.

Model farm production practices are typical of non-irrigated potato farms in the Red River Valley of North Dakota. In the fall prior to the potato crop, wheat stubble was tilled in using a disc, and chisel plowed. Fertilizer was applied according to soil test results. Potatoes were planted during the last two weeks of May, based on appropriate temperature and moisture conditions. Potatoes were planted using two 6-row planters, in 36 inch rows, with a seeding rate of 24 hundredweight (cwt) per acre. Seed was treated with a fungicide prior to planting. Insecticide and starter fertilizer were applied in-furrow at planting. Potatoes were hilled once in June prior to herbicide application. Harvest took place in late August and early September using two 4-row harvesters. Potatoes were hauled from the field using eight tandem axel trucks and hauled to a co-op owned storage and wash plant. They were washed and sorted by grade, to be sold in the fresh market.

Deterministic Budget

The model farm enterprise budget is intended to serve as a template for producers and is meant to be manipulated to suit individual conditions. The budget is organized in the following three sections: gross returns, operating inputs, and ownership costs (Table A1). The organization and format is similar to Patterson's (2013) costs and returns estimate. All values or costs are calculated on a per acre basis. Additionally, main sections provide the value of, or cost per, marketable cwt.

Gross Returns

Gross returns for the potato enterprise are the sum of revenue received from the sale of all marketable grades of potato. Tubers produced by the model farm were sized into one of three categories and sold in the fresh market based on these categories. The size designations are: size C tubers, being those smaller than 1.875 inches in diameter; size B ranging from 1.875 to 2.25 inches in diameter; and size A from 2.25 to 3.5 inches in diameter. The market also distinguishes Chef size as being those tubers larger than 3.5 inches; however, for simplicity in this simulation, all tubers over 2.25 inches in diameter were considered size A. Total yield and market price for each size class were considered variably and are discussed in detail in a later section.

Operating Inputs

Operating inputs are sometimes referred to as variable costs. These are costs and expenses that vary directly with the level of production engaged in for the year. Typically, these are actual cash expenses that must be paid throughout the year. These costs include seed, fertilizer, pesticides, hired custom operation, machinery maintenance and fuel, labor, rented storage, and wash plant costs.

Seed

Seed planted was field generation three Red Norland. Two-ounce seed pieces were planted every nine inches in 36 inch rows. Price for seed, seed freight, and seed cutting were arrived at through general consensus of surveyed growers.

Fertilizer

Fertilizer rates will vary from year to year, dependent upon the soil test and the producer's yield goals. Table A2 shows an average fertility application plan and cost of products. Like many of the input costs, the price paid for each of these products varies from grower to grower, depending on agreements with suppliers.

Pesticides

Pesticide expenses are summarized in the budget in the following four categories: herbicide, insecticide, fungicide, and desiccant. Table A3 shows all pesticide costs for the model farm calculated in a separate sheet from the budget, where they are broken down into individual products, their recommended rate, and the estimated cost of the product. These are not intended to serve as recommendations. The value on this budget line represents only the cost of the product. The cost of application is covered in another section.

Custom Application

Broadcast fertilization and pesticide application was custom applied. One fertilizer treatment took place in the early spring, at an estimated rate of $6.50 per acre (Table A2). All pesticide treatments were applied with a ground spray applicator at the same price rate as the fertilizer spreading ($6.50/acre) (Table A2). Soil testing was also included as a service in this section, and takes place for each potato field annually, at an estimated cost of $10 per acre (Table A2).

Machinery

Equipment costs summarized in the budget were calculated in separate spreadsheets represented in part in Tables A4, A5, and A6. Within these spreadsheets, costs were separated into two categories: cash overhead (fixed) (Table A4) and operating (or variable) (Table A5) expense. Cash overhead consisted of capital recovery costs, and a second category that combined taxes, insurance, and housing related to equipment. Capital recovery is the joint cost of depreciation and interest, and was calculated using a capital recovery factor, which is a function of interest rate and the economic life of the machine (Edwards, 2015). The annual capital recovery cost is found by multiplying the total depreciation (new price – salvage value) by the capital recovery factor, then adding that to the product of salvage value and interest rate (Edwards, 2015).

Capital recovery = (depreciation x capital recovery factor) + (salvage value x interest rate)

Edwards (2015) indicates that there is a tremendous variation in housing and insurance costs; however, to simplify, he combined them together as one percent of the average value of the machine.

Housing and insurance = 0.01 x (purchase price + salvage value) / 2

Operating costs are those costs that vary with the degree of usage of the machine, they are also sometimes referred to as variable costs. Operating costs were subdivided as repairs, fuel, and lubrication costs. Repair costs vary greatly due to many factors, such as management policies, soil type and terrain, rocks, and operator skill. The best data for estimating repair costs are records of producer's past repair expenses (Edwards, 2015). Due to the lack of historical repair costs for the model farm, repair expenses were estimated based on purchase price of the machine and estimated total hours of use. Accumulated repair cost is an upward sloping curve, indicating that repair costs are relatively lower early in the life of the machine and much higher on a relative basis as the end of the economic life of the machine is approached (Edwards, 2015). It is important to keep in mind that the annual repair cost calculated is an estimation of an average annual cost over the life of the machine. Edwards (2015) provides a table of accumulated repair costs as a percentage of list price, based on the type of machine and the accumulated hours of use. The annual repair cost is found by dividing the product of the list price and the percentage from the table, by the years of life (Edwards, 2015).

Annual repairs = (new list price x table value) / economic life

Fuel costs were calculated in two different ways depending on the type of machine. Fuel costs were assigned to each individual implement rather than to specific tractors, thus there was no fuel cost assigned to the tractors alone. For implements pulled by tractors, fuel was calculated in gallons per hour, by multiplying 0.044 by the maximum PTO horsepower of the diesel engine (Edwards, 2015). The product was multiplied by hours of use to obtain total annual consumption. For pickups and trucks, fuel consumption was calculated based on estimated miles driven and estimated average miles per gallon. Average fuel economy was estimated for the pickups as 12 miles per gallon, and 5 miles per gallon for the trucks. This value attempts to capture road miles, field miles, and idle time.

$$\text{Fuel cost}_{tractors} = 0.044 \times \text{maximum PTO horsepower} \times \text{annual hours of use} \times \text{diesel price per gallon}$$

$$\text{Fuel cost}_{trucks} = \text{miles driven} / \text{average miles per gallon} \times \text{fuel price per gallon}$$

Surveys indicate that lubrication costs for most farms are, on average, about 15% of fuel costs (Edwards. 2015). This factor was used as the basis for calculating lubrication cost for this farm.

Lubrication = 0.15 x total fuel cost

Equipment cash overhead and operating expenses (discussed above) were mostly calculated on a whole farm basis. A portion of each of these expenses was allocated specifically to the potato enterprise, based on the proportion of use in potato relative to the rest of the farm. For pickups and fuel and service trucks, it was estimated that approximately 40% of use was for potato operations, 40% of use was for the sugar beet enterprise, and 10% each was assigned to dry bean and wheat production.

Potato usage of pickups and fuel and service trucks = total usage / 2.5

Tractor total usage was calculated based on usage in the potato enterprise. Hours required for each operation in potato were calculated based on size of implement, speed of travel, and efficiency. Usage for the rest of the farm was estimated from this. Potato usage for tractor 1 was multiplied by 2.25, tractor 2 usage was multiplied by 2.50 because it is the primary tractor used in the other crops, and tractor 3 usage was multiplied by 2.00 because it is primarily only used in potato and sugar beet. Truck usage was calculated based on loads per day that could be hauled depending on the distance to the storage and the efficiency of both the harvest and unloading operations. It was estimated that usage in sugar beet would be roughly equivalent to the usage in potato, so potato usage was multiplied by 2.00 to obtain total farm usage (the tandem axel trucks on the model farm are only used in potato and sugarbeet production).

Total truck hours = potato loads per day x hours per load x potato harvest days x 2

Labor

Labor requirements were broken down into three categories: equipment operator, truck driver, and general laborer. Equipment operator hours were simply derived by multiplying the hours of use for each piece of equipment by a 1.15. This factor accounts for the additional labor hours that are required for things such as greasing and fueling equipment. Truck driver hours were calculated in a similar manner based on hours of truck use. Finally, general laborer hour requirements were assumed to be equal to 25% of the sum of all other labor. Hourly rates for each of the three divisions are based on estimated normal wages for the region (A. P. Robinson, personal communication, 2016).

Storage and Washing

Grower co-ops were consulted to obtain storage and wash plant expenses. The model farm does not own a storage or wash facility. These expenses are paid to the co-op. A flat rate of 90 cents per cwt is assigned for storage, and is charged based on the total yield out of the field. Wash plant charges are charged based on the marketable yield, with culls and shrink subtracted, as per the industry standard practice.

Other

Crop insurance is purchased by the acre for $120 (A. P. Robinson, personal communication, 2016). Potato fees and assessments are charged by state and national checkoffs. The total of the state and national checkoffs is around 8.5 cents per cwt of marketable potatoes sold from the wash plant (A. P. Robinson, personal communication, 2016). Operating interest is charged in the budget at a rate of 5% on all operating costs.

Ownership Costs

Ownership costs for an enterprise are those expenses that are incurred whether or not the crop is produced. These typically do not vary with output. Ownership costs related to machinery and equipment have been discussed previously. Land rent was estimated as the average rate that might be paid for a potato crop in the area. Even for a producer who may own all of his or her farm ground, it is important to consider land rent as an expense in the budget, because it is the opportunity cost that is incurred by growing the crop, rather than renting it out to another grower, or selling it.

The final ownership cost in the enterprise budget is the management fee. The management fee is the wage paid to the grower or the manager for the management of the operation. This is an important expense to include, even if the owner is the one who is providing the management, because it helps provide a clearer picture of the profitability of the enterprise, and accounts for the opportunity cost of the grower's time. The management fee for the model farm is equivalent to 5% of the operating costs (Patterson, 2013). It should be acknowledged that in practice, basing wages of management on actual expenses may not be the wisest strategy because it takes away some of the incentive for efficiency. This method was simply used to estimate a value that might be commensurate with the scale of the operation. There is much less variability in input costs than in revenue, and therefore they provide a more stable basis for estimation of the management fee.

Stochastic Factors

In reality, producers do not live in a deterministic, or fixed, world. Potato producers face uncertainty and risk from many sources. Some sources of risk are more volatile than others. Stochastic simulation was used to account for variability and risk. Stochastic values in the budget are represented by statistical distributions that capture the range of probable values rather than one fixed value. The stochastic factors in this analysis are yield and price by size grade of potato. The strength and dependability of a simulation lies largely in the reliability of the data from which distributions are defined. Efforts were made to obtain accurate historical data, representative of the region in consideration.

Price Data

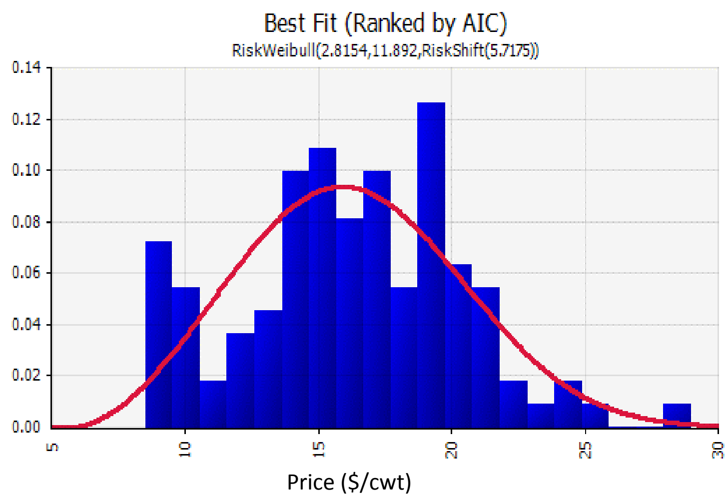
Prices used in this budget may or may not reflect actual prices received by commercial potato growers, due to differences in contracts or terminal markets. Within the fresh red potato market there is a wide range of prices received depending on the size classification of the potato, and the time of year they are marketed. Recently, the smaller B and C potatoes typically sell for a premium in the market, above the price of A size tubers.

Historical price data were obtained from the Northern Plains Potato Growers Association (NPPGA) for size A and size B red fresh potatoes. It provides a once a month snapshot of the fresh market prices for each month in the marketing year for the years of 2003 to 2016. The marketing year ran from September to May. The mean price of size A tubers for these years across all months was $16.31 per cwt, ranging from a minimum of $8.50, to a maximum of $29.00 per cwt. The mean price of size B tubers during this same time frame was $23.99 per cwt, with prices ranging from $11.50 to $39.75 per cwt (Table 1) (A. P. Robinson, personal communication 2016).

Table 1. Price statistics measured in $/cwt for red potatoes sold in the fresh market from 2003 to 2016 based on once a month snapshot for each month of the marketing year (September to May).

	Size A	Size B
Minimum	8.50	11.50
Maximum	29.00	39.75
Mean	16.31	23.99
St. Dev.	4.12	7.04

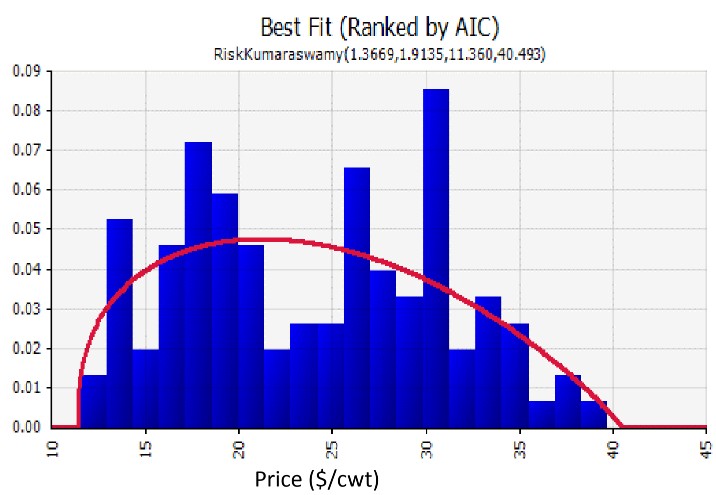
Historical data were analyzed using the *BestFit* function in the *@Risk* software package (Palisade Corporation, 2016). The *BestFit* function compiles data in a histogram and estimates a probability density function, then optimizes the goodness-of-fit of the data among a set of theoretical statistical distribution functions. Several goodness-of-fit statistics were utilized in order to determine the distribution function that most accurately represents the historical data. Based on this analysis, the best fitting statistical distribution to represent the price of size A potatoes was the Weibull distribution. The Weibull distribution is defined by a shape parameter (alpha), and a scale parameter (beta) (Palisade Corporation, 2016). The Weibull distribution fit to the historical data for the price of size A red potatoes is shown in Figure 1. The Kumaraswamy distribution was the best fit for the size B historical prices (Figure 2). The Kumaraswamy distribution is defined by two shape parameters (alpha 1 and alpha 2), and a minimum and maximum value (Palisade Corporation, 2016). It is very flexible, similar to the beta distribution. Historical price data were not available for C size potatoes. The price of these is represented in the budget by a specified premium added to the sampled B price. The premium is defined by an estimated triangular distribution with a minimum value of $15, a most likely value of $20, and a maximum value of $25 per cwt A positive correlation was discovered in the data between the price of A and B size potatoes, using the *Batch Fit* function in *@Risk*. *Batch Fit* allows for several ranges of data to be analyzed together for fit, and derives a correlation matrix if correlation is discovered between the variables. This correlation is accounted for in the stochastic model using the *RiskCorrmat* function. *RiskCorrmat* links distribution functions to a correlation matrix so that variable sampling is not treated independently.



Distribution Statistics

	Historical Data	Weibull
Minimum	8.50	5.72
Maximum	29.00	+Infinity
Mean	16.31	16.31
Mode	14.00 [est]	15.89
Median	16.38	16.16
Std. Deviation	4.12	4.07
Skewness	0.10	0.23

Figure 1. Historical size A prices for fresh red potatoes when grown in the Red River Valley of North Dakota or Minnesota and the best fit (Weibull) distribution.



Distribution Statistics

	Historical Data	Kumaraswamy
Minimum	11.50	11.36
Maximum	39.75	40.49
Mean	23.99	23.96
Mode	13.50 [est]	21.21
Median	24.25	23.55
Std. Deviation	7.04	6.96
Skewness	0.13	0.20

Figure 2. Historical size B prices for fresh red potatoes when grown in the Red River Valley of North Dakota or Minnesota and the best fit (Kumaraswamy) distribution.

Yield Data

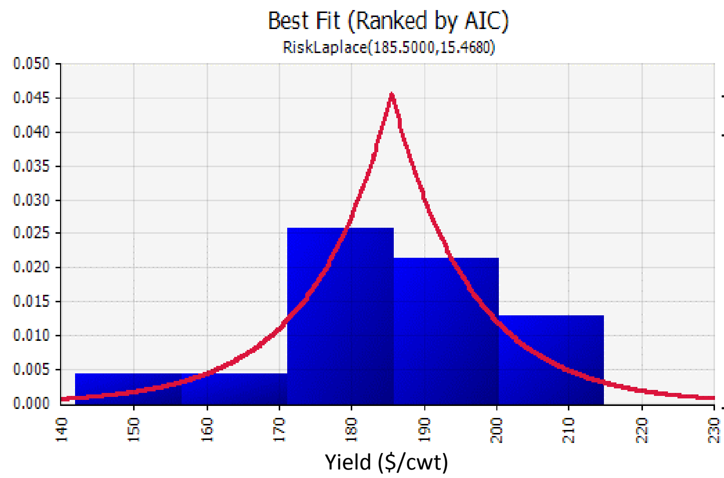
Reliable yield data for potato is difficult to obtain because there is substantial variability in yields between different fields, producers, and regions of the state. The best yield data to use would be historical yields for the particular farm being simulated. However, since this information is not available for the model farm, yield data was obtained from the United States

Department of Agriculture (USDA) National Agricultural Statistical Service (NASS) for potatoes grown under non-irrigated conditions in North Dakota from 1994 to 2009. Yield data from more recent years would have been preferred; however, these were the most up to date potato data available from NASS for North Dakota. During this time period the mean yield in North Dakota for potatoes grown under non-irrigated conditions was 186 cwt per acre. Non-irrigated yields ranged from 142 to 215 cwt per acre (USDA, 2016).

Table 2. Yield statistics for non-irrigated potatoes grown in North Dakota from 1994 to 2009 (USDA, 2016).

	Yield in cwt/acre
Minimum	142
Maximum	215
Mean	186
Std. Dev.	19.9

Laplace is the best distribution function for the historical data according to all goodness-of-fit statistics employed (Figure 3). Laplace is a sharp peaked distribution with long tails. It is defined by the location parameter (mu) and the scale parameter (sigma). The yield value defined by this distribution is the total yield at the field's edge given in cwt per acre. Various growers were consulted and it was estimated that about 12% of the total yield would be culls, and thus unmarketable. In addition, another 12% would be lost to shrinkage during storage. These losses leave 76% of the total yield out of the field as marketable. Of that portion it was estimated that 75% would be size A, 20% would be size B, and 5% would be size C. There can be some variability in this breakdown of total yield, and additional work might be done to consider these percentages stochastically in the future. However, in this analysis, only total yield is stochastic and the breakdown by size is treated deterministically.



Distribution Statistics

	Historical Data	Laplace
Minimum	142.00	-Infinity
Maximum	215.00	+Infinity
Mean	185.94	185.50
Mode	185.00[est]	185.50
Median	185.50	185.50
Std. Deviation	16.86	15.47
Skewness	(0.69)	-

Figure 3. Historical yield of non-irrigated potatoes in North Dakota in cwt per acre, and the best fit (Laplace) distribution (NASS, 2016).

Simulation

The stochastic simulation model is specified as

$$NR_i = \tilde{P}_i \tilde{X}_i - VC - FC,$$

Where NR_i is the net return of simulation i, $\tilde{P}_i$ and $\tilde{X}_i$ are the simulated stochastic prices and yields, VC is the variable cost, and FC is the fixed cost. The stochastic factors were defined by their distribution functions; output for the simulation was specified as net returns above total cost per acre. *@Risk* was used to simulate the model with 5,000 iterations, yielding 5,000 unique net returns, based on the random sampling of the stochastic inputs.

Results and Discussion

Most farming operations prepare a *pro forma* budget when they are planning for the upcoming year. These budgets are nearly always deterministic in nature, and as such, only capture a single snapshot of a possible outcome, when in fact, there is a very wide range of possible outcomes due to many factors outside of the grower's control. This variability is particularly profound in potato production. Initial preparation of a deterministic budget yielded a net return above total cost of $205 per acre, or $102,500 for the five-hundred acre potato enterprise on the model farm. This may seem like a favorable return to a producer; however, if the grower is not aware of the level of risk that exists in the enterprise and makes decisions based solely on the outcome of the deterministic budget, without a way to quantify and understand the risk involved, the grower could face a financial catastrophe.

Distribution of Simulated Net Returns

Nearly any potato producer will understand that there is a certain amount of risk involved in growing and selling a potato crop. The results of the stochastic simulation helps potato growers understand the level of the risk by quantifying the range of net returns and their probability of occurrence. The output (net return) of each of the 5,000 iterations in the simulation were compiled into a histogram by *@Risk*, allowing for easy analysis of the results. Figure 4 is a histogram representation of the net returns received for each iteration. Individual producers will have differing input costs, which may shift the location of the curve, but the shape would remain the same unless distributions for price or yield were changed. The shape and spread of the distribution of net returns is probably the most informative piece of this picture with respect to risk. The mean net return in the simulation was $205 per acre. The standard deviation of the output is $638 per acre. The magnitude of this variation is better comprehended when it is considered that the range of net returns of -$433 to $843 per acre lies within plus or minus one standard deviation of the mean. That is a difference of $638,000 for the entire enterprise. Standard deviation provides a useful value for understanding the level of variability, which is often closely associated with the level of risk (Palisade Corporation, 2016). It provides one means of comparing the enterprise with other investment opportunities when discussing risk management. The net returns for the enterprise do not breakeven 39% of the time (Figure 4). Losses as great as $1,324 per acre were observed in the simulation, equating to a loss of $662,000 for the entire potato enterprise. Simulated net returns fall below zero, nearly 40% of the time, thus a savvy producer must manage risk by being prepared to lose money with their potato crop two years out of five. Potato producers may be optimistic based on the output distribution, as it is skewed right, and the upside potential is greater than the downside potential. The maximum net return observed in the simulation was more than twice as large as the greatest loss, yielding $2,757 per acre, or $1.38 million, for the enterprise.

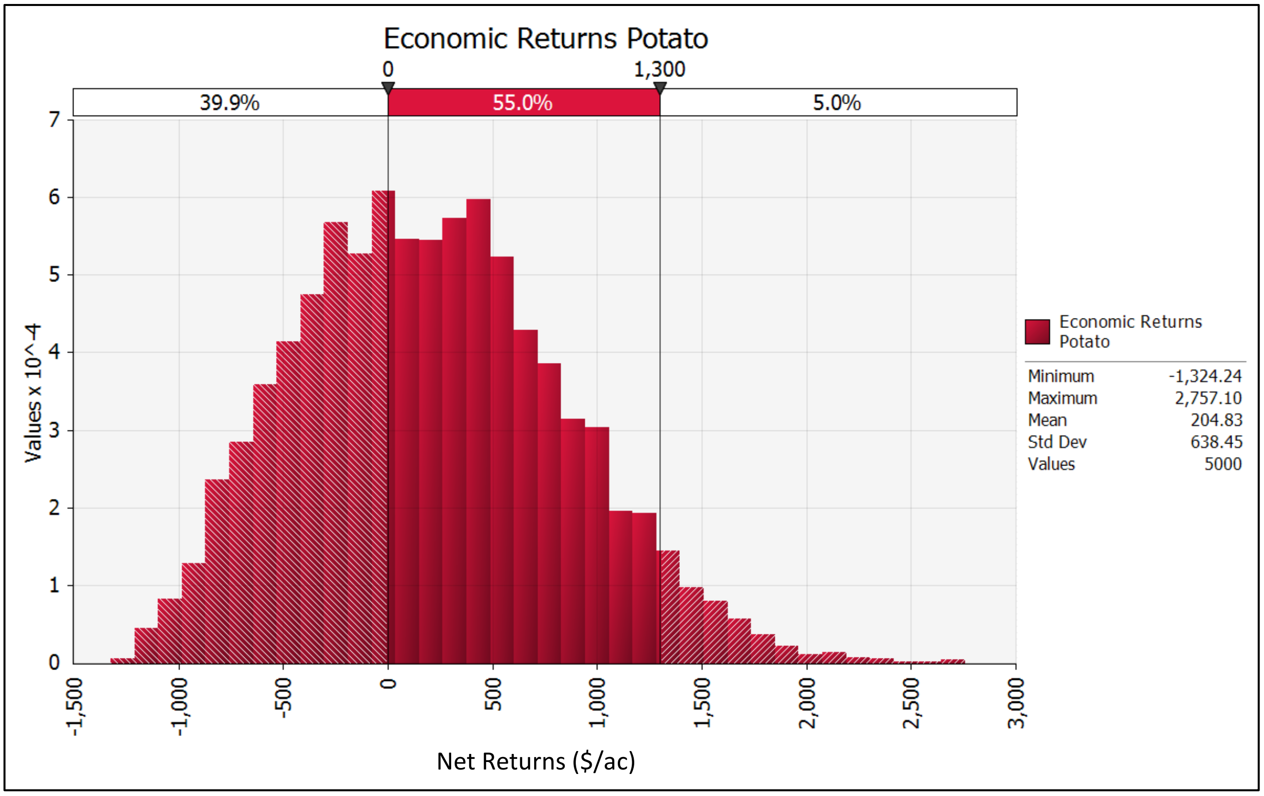


Figure 4. Probability density of simulated net returns, in dollars per acre, of non-irrigated red potatoes, in the Red River Valley of North Dakota, based on stochastic price and yield.

BestFit was used to fit a distribution to the output results for net returns. The Weibull distribution provides the best fit. Typically, a farmer might expect his or her returns to be somewhat normally distributed. From a risk management planning standpoint, the differences between a normal and Weibull distribution would be fairly subtle (Figure 5). An assumption of normally distributed returns might slightly overestimate potential losses, which may be beneficial to the risk averse decision maker when planning for the future.

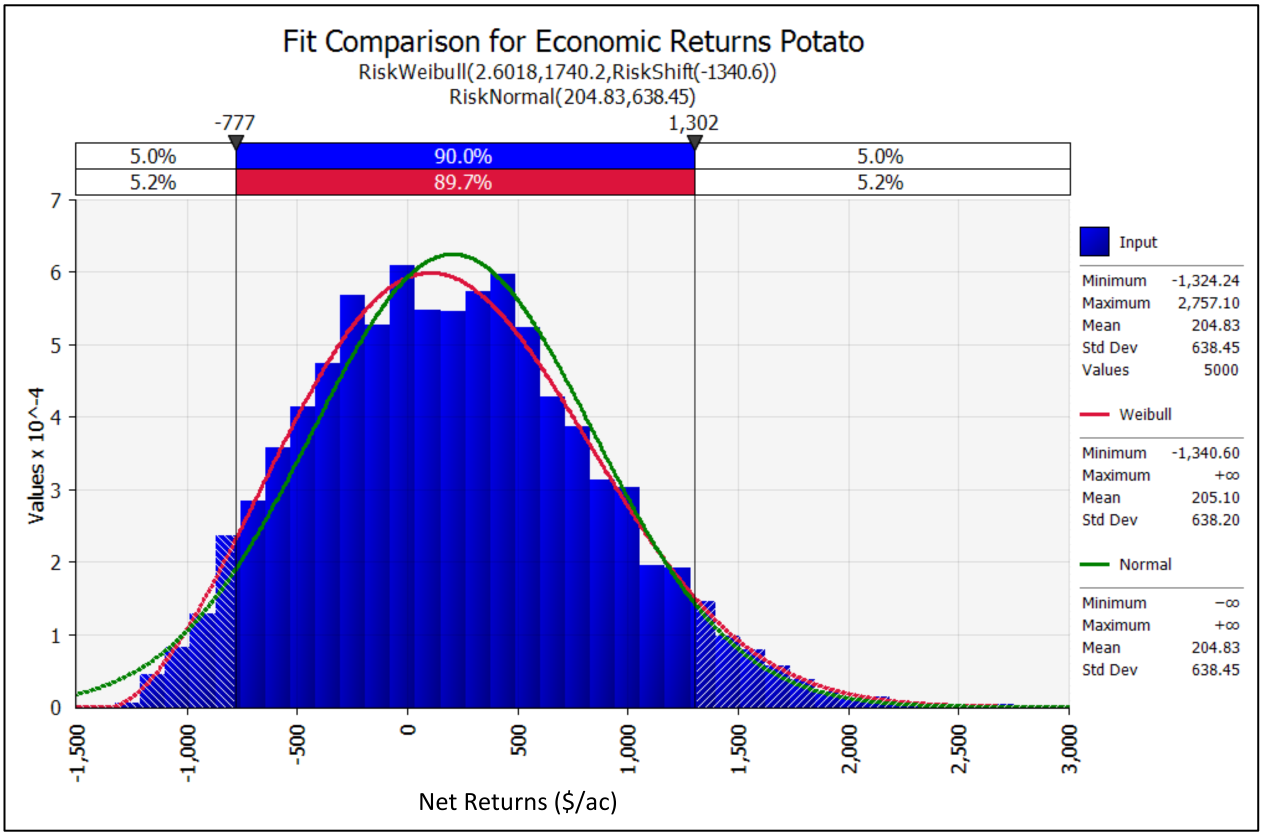


Figure 5. Weibull and normal distributions fit to the output results for net returns of non-irrigated red potatoes in the Red River Valley of North Dakota.

A Wheat Comparison

In order to put the range of simulated potato returns into perspective, a similar, simplified analysis was conducted on hard red spring wheat. Wheat was chosen because it is another crop grown by the model farm and is typical in the crop rotation, with potatoes, in North Dakota. An enterprise budget for wheat was obtained from the North Dakota State University Extension Service (Swenson and Haugen, 2015). Price and yield were defined stochastically in the enterprise budget with normal distributions. Ten years of data were collected from the USDA (2016) NASS quick stats, in order to derive a mean and standard deviation for the price and yield of hard red spring wheat in ND.

Simulated net returns for wheat where much more tightly clustered around the mean than the net returns for potato (Figure 6). Wheat did not have the large chance of substantial losses that were present in potato; however, there was not the same possibility for large returns on the upper end either. Values representing the greatest 5% of losses in wheat are surpassed with potato 33% of the time. Conversely, values representing the most profitable 5% of years in wheat, are exceeded by potato nearly half of the time (49%). The difference in the volatility of net returns is apparent in the standard deviation. The standard deviation for potato net returns is $639 per acre, while the standard deviation for the net returns of wheat is $87 per acre. The value of one standard deviation is $276,295 greater for the 500 acre potato enterprise than for the 500 acre wheat enterprise.

Magnitude of Input Effect on Net Returns

The tornado graph represents the magnitude of the effect of each of the four stochastic inputs (A, B, and C price and total yield) on net returns (Figure 7). It may not be surprising that the market price of size A red potatoes has the largest impact on the variability of net returns. Three quarters of the marketable yield is estimated to be of this size, indicating that a change in the price of size A potatoes would drive a greater change in net returns than a proportional change in another variable such as yield. Considering the magnitude of the effect of A price on net returns, it is not surprising that the distribution of the output (net returns), has a similar shape

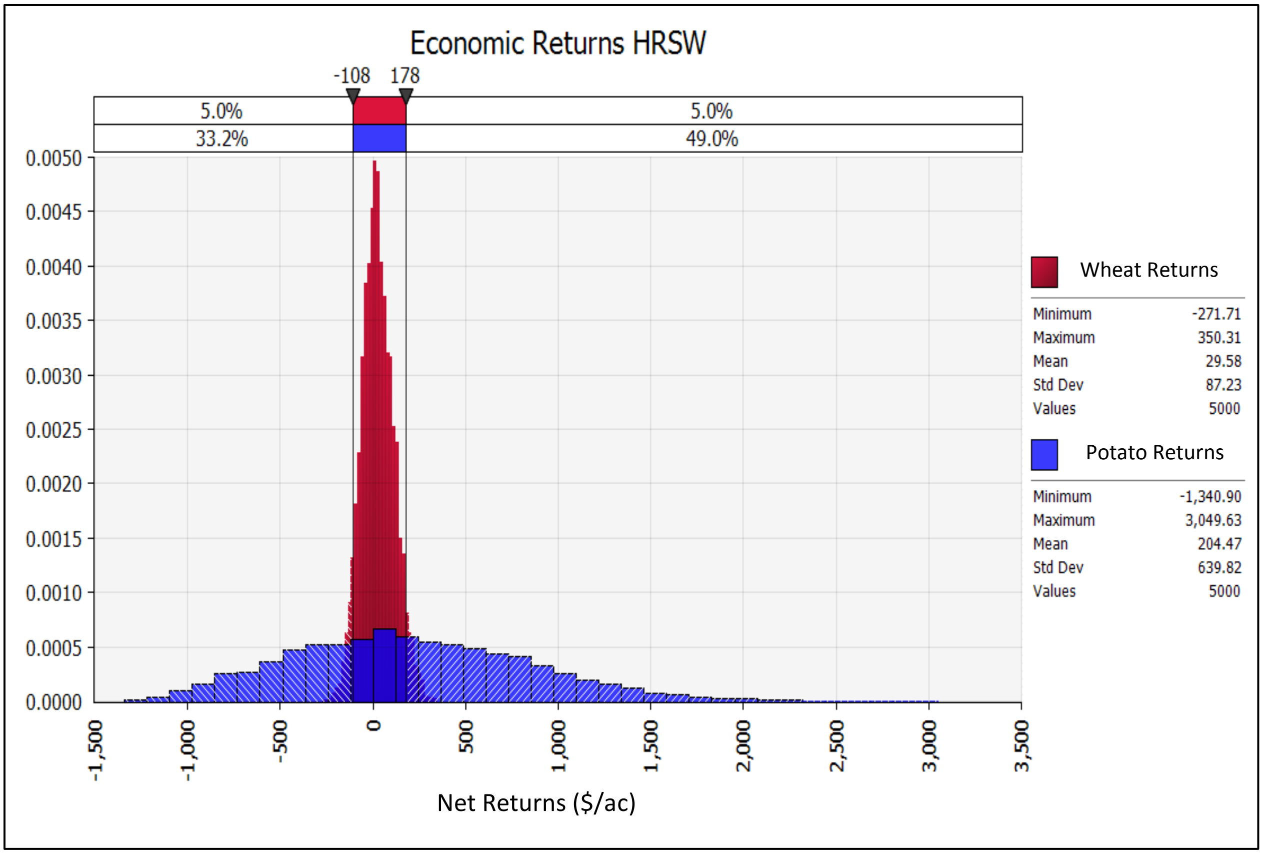


Figure 6. Overlaid probability density of net returns for hard red spring wheat and non-irrigated red potato.

as the distribution specified as the input for the price of A sized potatoes. Size B follows, and overall yield is a distant third, in terms of its effect on net returns. The effect of the price of the A size, is more than three times larger than that of overall yield. Despite the large premium often received for C size potatoes, the price of these has very little effect on the variability of the net return. This is likely due to C size tubers making up a small percentage of the overall yield.

From a risk management perspective, these results suggest that the best use of time might be spent pursuing methods to manage price risk in the market. Obviously, the health and yield of the potato crop should not be neglected, but if the goal is to manage and minimize the level of risk the potato enterprise is exposed to, then the creative entrepreneur should seek out ways to manage price risk through whatever means possible. A few of these tools might include contracts, direct marketing, and/or insurance (Harwood et al., 1999).

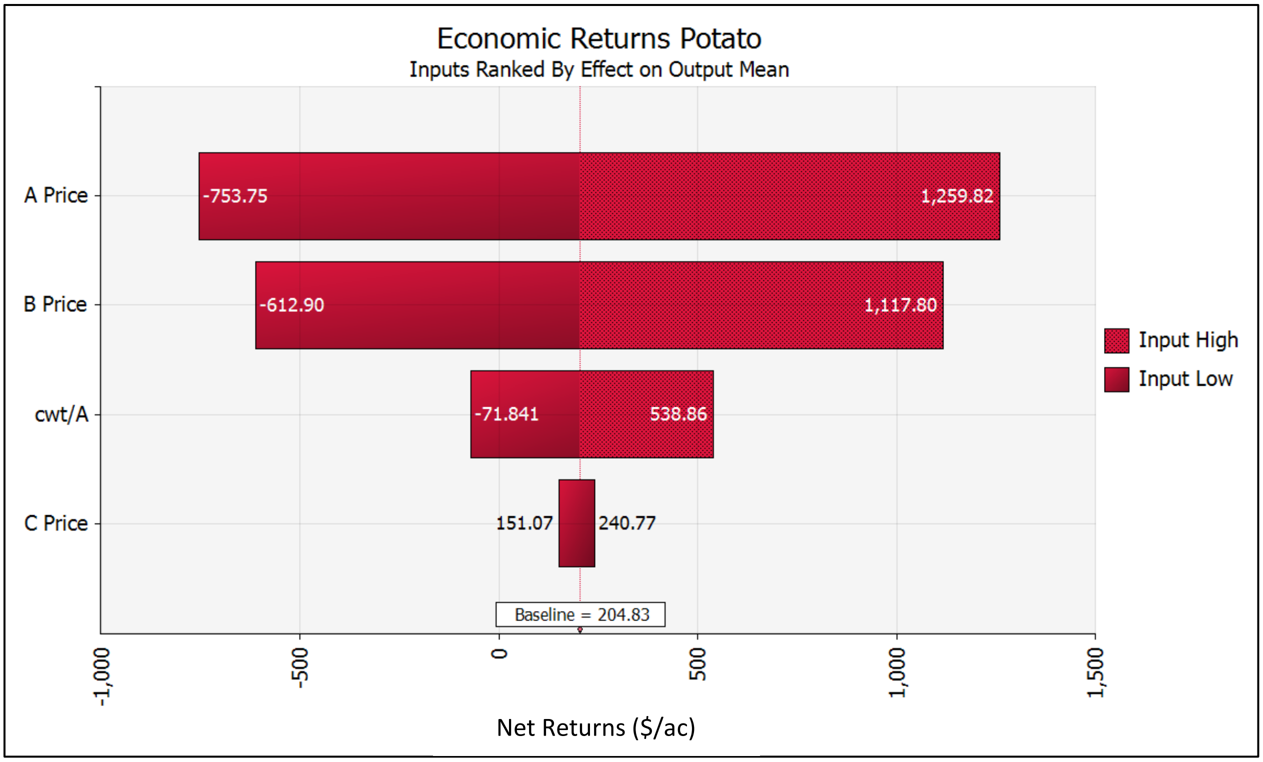


Figure 7. Tornado graph of the magnitude of the effect of each stochastic input (A, B, and C price and yield) on net returns ($/ac) for non-irrigated red potato production in the Red River Valley of North Dakota.

Conclusion

It is a commonly accepted fact, that non-irrigated potato production in the Red River Valley is a risky endeavor; however, the meaning of this statement is somewhat subjective and does not provide any indication of the level of risk involved, or how it may compare with another enterprise that the farm might invest in. A deterministic enterprise budget is an important starting point in seeking to understand what is at stake financially; however, it only provides a snapshot of one possible outcome. In reality, certain elements of the budget are variable and unpredictable, thus the returns expected are variable and unpredictable. Stochastic (or Monte

Carlo) budgeting uses simulation to account for the variability, or risk, within the budget. Risky elements are considered as ranges of possible values rather than fixed amounts.

Price and yield are some of the most unpredictable or risky budget components, with the greatest effect on net returns. Ranges of values for prices were obtained largely from monthly historical prices for red potatoes in the Red River Valley. The fresh market is quite volatile and the range of prices varied tremendously over the time frame considered. Total yield also varied significantly, due, speculatively, to the unpredictability and unreliability of the weather and other challenges with producing non-irrigated potatoes. The volatility in price and yield, makes stochastic budgeting a valuable tool for potato producers to evaluate risk.

Simulation of the non-irrigated red potato enterprise on the model farm yielded a positive mean net return, but also had a high standard deviation for net returns, making it difficult to predict positive returns consistently from year to year. Variability in the prices of A and B sized potatoes were the greatest factors in determining the variability of returns. A risk averse manager would most efficiently allocate risk management efforts to managing exposure to price risk through the utilization of contracts, direct marketing, insurance, and/or any other means available. The health and yield of the crop should not be neglected, but it is responsible for much less risk to net returns. The authors do not attempt to classify non-irrigated red potato production as strictly low or high risk; however, these values provide a metric with which to measure the enterprise against others where resources might be devoted, to form a relative ranking of risk. Every decision maker has unique risk preferences based on their position and appetite for risk. Individual preferences for each party invested in the success of the enterprise should be understood and accounted for by the decision maker seeking to manage risk and maximize returns.

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IRRIGATED RUSSET POTATO PRODUCTION AND RISK

Abstract

Potato production is a risky enterprise. This statement, while generally accepted as truth, is rather vague and could mean many different things to different individuals. This study sought to quantify this statement, such that a producer could rank potato enterprise risk against other opportunities. North Dakota State University does not currently have a published enterprise budget for irrigated russet potato production. An enterprise budget was created based on a hypothetical model farm in southeastern North Dakota. Distributions were derived for the budget to represent ranges of possible prices and yield. These distributions were sampled randomly in a Monte Carlo simulation, with 5,000 iterations, to derive a range of possible net returns in order to quantify the risk the enterprise is exposed to. The mean net return was $384 per acre, with a standard deviation of $430 per acre.

Introduction

North Dakota ranks fourth in the U.S. in potato production volume. Potatoes generated more than $258 million in production value in the state in 2015 (National Potato Council, 2016). Potatoes are a high input crop requiring frequent chemical treatments, specialized equipment, expensive climate controlled storages, and careful handling to preserve quality. An enterprise budget is an important financial tool for a farm to assess the year and make plans for the future. Enterprise budgets exist for irrigated potato production in other regions of the U.S., but North Dakota does not have a current published budget specific to the region.

An enterprise budget is a financial statement reflective of all costs and revenues associated with a particular enterprise for a given financial period, such as a year. Unlike a whole farm budget, it is not representative of the profitability of the entire farm, but only of the specific enterprise, considered in isolation. The costs of some resources, such as tractors or tillage implements are shared among multiple enterprises across the farm. In these cases, costs are allocated proportionately according to their level of use in each enterprise. An enterprise budget enables a producer to analyze each operation independently of others on the farm in order to ensure wise allocation of resources across the farm. Published potato enterprise budgets exist for other states (Patterson, 2013; Galinato and Tozer, 2016; Bogash et al., 2013), but there is no published enterprise budget for irrigated potato production in North Dakota.

Although a traditional enterprise budget is a valuable tool, its relevance in risk management is somewhat limited, in that it only represents a single, fixed scenario; however, it provides a starting point for additional analysis. There are many unpredictable factors, outside the control of the producer, that lead to variability and risk within the budget. It has often been said that potato production is a “high risk, high reward” business, but what does that actually mean? Commercial potato production does present a high degree of risk, due to high input costs, variable yields, volatile markets and susceptibility to many economically damaging pests. The recent reduction in overall commodity prices has increased the awareness of managing risk and maintaining sustainable profit margins. When seeking to manage risk, it is important first, to define what risk is in the context of an agricultural enterprise.

Risk is a much discussed subject within the field of economics; however, there is not a single accepted definition of the term. The word risk is often used synonymously with the word uncertainty, to describe a situation where the outcome is unknown. Knight (1921), and subsequent researchers, suggested a distinction between these two terms based upon information available from similar past situations. Knight proposed that a risky decision is one in which the decision maker faces a choice with multiple possible outcomes, and a similarity to past events, so that a probability density may be generated for the occurrence of a given outcome. Additionally, if facing a unique situation with multiple outcomes and no precedent, the decision maker faces uncertainty (Knight 1921). Knightian risk is measurable, while uncertainty is immeasurable, and thus impossible to calculate. Risky decisions, events, or outcomes can be graded as more risky or less risky than another, while uncertain events cannot.

Robinson and Barry (1987) pointed out that decision makers must often make probability judgments with little or no empirical support or precedent. These would be situations that Knight would consider uncertain; however, once the judgment has been made by the decision maker, the decision making process is nearly the same, whether facing risk or uncertainty (Robinson and Barry 1987). For this reason, many economists do not maintain the distinction between risk and uncertainty, and often use the terms interchangeably. Robinson and Barry (1987) go on to propose the importance of distinguishing between the two terms. “[They] define as risky those uncertain events whose outcomes alter the decision maker’s well-being” (Robinson and Barry 1987). This is different than the definition proposed by Knight (1921) and others where the two terms are mutually exclusive. Instead, based on Robinson and Barry’s (1987) definition, risky events are a subset of uncertain events, with an uncertain event being those whose outcome is not known with certainty.

Agricultural producers are subject to a high degree of risk due to many factors such as the biological nature of the production process, short run inelastic supply and demand, and variances of weather (Myers et al. 2010). It is important for producers to understand the concept of risk, and the degree to which their enterprise or business is exposed, in order to be successful in agricultural markets. Even with all the same information, sometimes individual producers make different decisions under similar circumstances. This is due to differences in risk preferences among producers and the probability they assign to future events (Kazmierczak and Soto 2001). It is important for a producer to understand his or her individual risk preferences. Risk preferences are based on the level of risk aversion felt by an individual, and varies from person to person. Some of the factors that influence risk aversion are age, wealth, income, and education (Riley and Chow, 1992). Some method or means of quantifying risk is needed to enable producers to rank potential “risky” decisions from least risky to most risky, in order to make informed decisions, based on their individual risk preferences.

Monte Carlo simulation, also known as stochastic simulation, provides one means of analyzing potential risky decisions. “Monte Carlo simulation encompasses any technique of statistical sampling employed to approximate solutions to quantify problems” (Kwak and Ingall 2007). This type of simulation begins with the development of a model, representative of a real-life scenario. One or more of the model inputs are “risky” variables, defined by a specified statistical distribution, representative of the range of probable values for that input. There are a number of distribution shapes that may be used, such as normal, beta, triangle, uniform, and others. Once the model is developed and the distributions defined, computer software is used to run the simulation, randomly sampling values from the distributions and running them as inputs in the model. This process takes place a large number of times, or iterations. Each iteration represents a possible outcome for the model. The range of outputs, across all iterations can then be compiled into a distribution, to indicate not only what may happen, but also how likely it is to happen, based on the probabilities assigned to the inputs. This provides a metric with which to rank potentially “risky” decisions, from least risky to most risky, relative to one another. Khabkazan *et al.* (2014) used stochastic budgeting to analyze financial benefits and risk levels of alternative calving schedules in Canadian beef production. Monte Carlo simulation can be a very powerful tool in trying to understand the potential effects of uncertainty and risk, but it is only as good as the model it is simulating and the information that is fed into it (Kwak and Ingall 2007). It is important to seek out the best data and other information when fitting the distributions from which to sample.

Stochastic simulations begin with a fixed or deterministic model. Once the deterministic model is developed, simulation can begin by identifying risky variables and replacing their fixed values with stochastic distributions. Potato growers are exposed to risk from a myriad of sources. Weather is capricious; potatoes are a susceptible host to a variety of insects and harmful diseases; there are wide and unpredictable market fluctuations; consumer perceptions and unfavorable public policy can drive market declines; input costs are high and may vary without respect to potato price; and markets can shift due to changes in technology and consumer preferences. Within the construct of an enterprise budget, many of the most impactful risks faced by producers could be represented directly or indirectly in yield and price received.

The first objective of this study was to develop a deterministic enterprise budget for irrigated russet potato produced for the processing market based on a representative model farm of a size and scale typical to a North Dakota farm outside the Red River Valley. The second objective was to utilize the deterministic enterprise budget to build a stochastic budget with which to simulate and quantify the level of risk involved in irrigated potato production.

Materials and Methods

Model Farm

A model farm was created in order to estimate the cost of production for irrigated russet potatoes produced for the processing market. Producers operate under unique conditions with varying operating costs and marketing channels. The model farm budget is intended to serve as a template and is meant to be manipulated by the grower to suit their individual conditions. The 8,000 acre model farm is meant to be typical of the size and scale that would be found in ND outside the Red River Valley, but it is not intended to represent an individual grower. The soil type is a sandy silt loam with a normal seasonal (May through August) rainfall of 12.3 inches (NDAWN, 2017). The farm utilizes center pivot irrigation. The crop rotation is potato, followed by corn, soybean, and wheat, for one year each. The model farm was designed to plant 2,000 acres of each crop annually.

Production practices of the model farm are typical of irrigated farms in ND. In the fall prior to the potato crop, wheat stubble is tilled in using a disc and chisel plowed. In the late fall, soil is deep-shank fumigated with metam sodium. Fertilizer is applied in the spring prior to planting, based on soil test results. Potatoes are planted from late April to early May, based on appropriate temperature and moisture conditions, at a seeding rate of 19 hundredweight (cwt) per acre, in 36 inch rows, using four 6-row planters. Seed is treated with a fungicide prior to planting. Insecticide and starter fertilizer is applied in-furrow, at planting. Potatoes are hilled and fertilized once in late May or early June prior to herbicide application. Harvest takes place in September, using six 4-row harvesters. Potatoes are hauled from the field using eighteen, tandem axel trucks and transported to storage facilities. They are sold to a potato processor for use in the frozen French fry market.

Deterministic Budget

The budget follows a common financial organization with the following three sections: gross returns, operating inputs, and ownership costs (Table A7). Each of these sections are discussed in detail below. The organization and format of the budget is similar to Patterson's

(2013) costs and returns estimate. All values or costs were calculated on a per acre basis. Additionally, main sections provide the value of, or cost, per marketable cwt

Gross Returns

Gross returns for the potato enterprise are the sum of revenue received from the sale of all marketable tubers. Yield and price received are considered variably and will be discussed in more detail in a later section.

Operating Inputs

Operating inputs are costs incurred with relation to the level of production engaged in. These are often referred to as variable costs, because they vary with production, unlike fixed costs, which are incurred regardless of production. These are typically actual cash expenses incurred throughout the year. The model farm enterprise budget includes the following categories of operating inputs: seed, fertilizer, fumigation, pesticides, hired custom operations, machinery maintenance and fuel, labor, and storage costs.

Seed

Russet Burbank is the world’s foremost French fry processing cultivar (Bethke et al., 2014). The model farm plants field generation three, Russet Burbank seed. Two-ounce seed pieces are planted every 12 inches in 36 inch rows. Price for seed, seed freight, and seed cutting were arrived at through general consensus of surveyed growers.

Fertilizer

Actual fertilizer application rates are determined based upon the soil test results, and the producer’s yield goals, thus they often vary from year to year. An average fertility treatment plan for irrigated russet potatoes, and cost of products applied, for the model farm is presented in Table A7.

Fumigation

The soil is fumigated with metam sodium at a rate of 50 gallons per acre (Amvac Chemical Corporation, 2015). The cost of the product is estimated at $6 per gallon (Table A7). The treatment method is to apply the product with deep injection shanks at 6 and 10 inches in order to place it in the root zone of the potato. Due to the specialized equipment and licensing required, custom application is hired at a rate of $60 per acre (Table A7). The cost of the custom application is maintained under the fumigation heading, rather than the custom heading, so that fumigation practices can be evaluated independently of other inputs.

Pesticides

Pesticide expenses are summarized in the budget under the following four categories: herbicide, insecticide, fungicide, and desiccant. A full breakdown of the model farm pesticide program, complete with rates and prices is provided in the appendix (Table A11). The value on the pesticide budget line is a summary of this information, and represents only the cost of the product, it does not include the application cost.

Custom Application

Broadcast fertilization, pesticide application, and fumigation is custom applied in the model farm potato enterprise. A pre-plant fertilizer treatment takes place in the early spring at an estimated rate of $6.50 per acre (Table A7). Pre-emergent pesticide treatments are applied with a ground spray applicator at the same price rate as the fertilizer spreading ($6.50/acre). All in-season fungicide treatments are applied aerially, as is customary for most ND processing potato production operations, at a custom rate of $8.00 per acre (Table A7). Soil testing is also included as a service in this section, and takes place annually for each potato field, at an estimated cost of $10 per acre (Table A7).

Machinery

The calculation of machinery costs related to the model farm potato enterprise is represented in part in Tables A4, A5, and A6. Within these spreadsheets machinery costs were separated into two general categories: cash overhead (fixed) (Table 10) and operating (or variable) (Table 11) expenses. Cash overhead consisted of capital recovery costs, and a second category that combined taxes, insurance, and housing, related to equipment. Capital recovery is the joint cost of depreciation and interest, and can be calculated using a capital recovery factor, which is a function of interest rate and the economic life of the machine (Edwards, 2015). The annual capital recovery cost is found by multiplying the total depreciation (new price – salvage value) by the capital recovery factor, then adding that to the product of salvage value and interest rate (Edwards, 2015).

Capital recovery = (total depreciation x capital recovery factor) + (salvage value x interest rate)

Edwards (2015) indicates that there is a tremendous variation in housing and insurance costs; however, to simplify, he combined them together as one percent of the average value of the machine.

Housing and insurance = 0.01 x (purchase price + salvage value) / 2

Operating costs are those costs that vary with the degree of usage of the machine; they are also sometimes referred to as variable costs. Operating costs are split into the following three sub-categories: repairs, fuel, and lubrication costs. There are many factors that cause repair costs to vary, such as management policies, soil type and terrain, rocks, and operator skill. For this reason Edwards (2015) indicates that the best data for estimating repair costs are records of a producer's own past repair expenses. This information was not available for the model farm, so repair expenses were estimated based on purchase price of the machine and estimated total hours of use. Accumulated repair cost is an upward sloping curve, indicating that repair costs are relatively low early in the life of the machine and much higher, on a relative basis, near the end of the economic life of the machine (Edwards, 2015). In light of this, it is important to keep in mind that the annual repair cost calculated is an estimation of an average annual cost over the life of the machine. Edwards (2015) provides a table of accumulated repair costs as a percentage of list price based on the type of machine and the accumulated hours of use. The annual repair cost is found by dividing the product of the list price and the percentage from the table by the years of life (Edwards, 2015).

Annual repairs = (new list price x table value) / economic life

Two different methods of calculating fuel costs were used, dependent upon the type of machine. Fuel costs were assigned to each implement, rather than to a specific tractor, thus no fuel cost is assigned to the tractors alone. Fuel use for operations with implements drawn by a tractor were calculated in gallons per hour, by multiplying 0.044 by the maximum PTO horsepower of the diesel engine (Edwards, 2015). The product was multiplied by hours of use to obtain total annual consumption. Fuel consumption for trucks and pickups was a function of estimated annual miles driven, and average fuel economy. Fuel economy was estimated for the pickups as 12 miles per gallon. Fuel economy was estimated at 5 miles per gallon for the trucks. This value attempts to capture road miles, field miles, and idle time.

$$\textit{Fuel cost}_{tractors} = \textit{0.044 x maximum PTO horsepower x annual hours of use x diesel price per gallon}$$

$$\textit{Fuel cost}_{trucks} = \textit{miles driven / average miles per gallon x fuel price per gallon}$$

Surveys indicate that lubrication costs for most farms are on average about 15% of fuel costs (Edwards, 2015). This was used as the basis for calculating lubrication cost for this farm.

Lubrication = 0.15 x total fuel cost

Machinery cash overhead and operating expenses, discussed above, were mostly calculated on a whole farm basis. The amount of these expenses allocated to the potato enterprise was proportional to their level of use in the potato enterprise, relative the use in the other farm enterprises. It was estimated that approximately 50% of the use of pickups, fuel trucks, and service trucks occurred in the potato enterprise, while the other 50% was allocated evenly among the remaining three crop enterprises on the farm (corn, soybean, and wheat).

Potato usage of pickups and fuel and service trucks = total usage / 2

Total tractor usage across the whole farm was estimated based on the hours of use in the potato enterprise. Usage for each potato operation was calculated as a function of implement size, speed of travel, and efficiency. Usage for the rest of the farm was estimated from this. Potato usage for tractors 1 and 2 was multiplied by 5.00, because these are the tillage and grain planting tractors and get used extensively across the entire farm. Tractor 3 potato usage was multiplied by 1.25, because it is used nearly exclusively in potato, with only a few other odd tasks around the farm. Potato usage of tractors 4 and 5 was multiplied by 2.50 to account for use in the other row crops on the farm. Finally, tractors 6, 7, and 8 were used exclusively in potato operations, so the total annual use is equal to annual hours of use in the potato enterprise.

Truck usage was calculated based on loads per day that could be hauled depending on the distance to the storage and the efficiency of both the harvest and unloading operations. The tandem axel trucks are used exclusively in the potato operation so the potato use of these trucks is equal to the total farm use.

Total truck hours = potato loads per day x hours per load x potato harvest days

Irrigation

Potatoes require between 18 and 36 inches of seasonal water (Bohl and Johnson, 2010). Precipitation will provide some of the water required; however, the timing and volume of rain events is unpredictable. Twenty inches of irrigation was selected as the amount to plan for in the budget, so that at least the minimum water requirement was guaranteed, without accounting for precipitation. Actual irrigation usage varies greatly from year to year, due to precipitation amounts, day and night temperature, and cultivar. Water permit and irrigation power costs were combined, for a value of $5 per acre-inch of water delivered (A. P. Robinson, personal communication, 2016). Irrigation repair costs are closely tied to the level of use, repair costs are also calculated based on irrigation water usage. Repair costs were estimated to be $0.50 per acre-inch (Patterson, 2013).

Labor

Labor costs were separated into the following four categories with differing pay rates: equipment operator, truck driver, general laborer, and irrigation labor. Equipment operator hours was equal to the sum of hours of use for each piece of equipment, plus an additional 15% to account for time spent on activities such as greasing and fueling the machinery. Truck driver hours were calculated in a similar manner based on hours of truck use. Irrigation labor for the season was estimated to be equal to one hour per acre to operate and maintain the center pivots. General laborer hour requirements were assumed to be equal to 25% of the sum of all other labor. Hourly rates for each of the four divisions are based on estimated normal wages for the region (A. P. Robinson, personal communication, 2016).

Storage

The cost of potato storage is highly variable, depending on the length of storage, and the condition of the facility. Potato storage could be considered a separate enterprise unto itself, and determination of all storage related costs was beyond the scope of this study. Although a typical ND potato grower would usually own on-farm storage facilities, a simple storage rental rate was used in the model farm enterprise budget. Grower co-ops were consulted to determine an average rental rate for potato storage. A flat rate of 90 cents per cwt is assigned for storage and is charged based on the total yield out of the field.

Other

The model farm purchased crop insurance at a cost of $120 per acre (A. P. Robinson, personal communication, 2016). Potato fees and assessments are charged by state and national checkoffs. The total cost of checkoffs is around 5.5 cents per cwt of marketable potatoes sold to a processor (A. P. Robinson, personal communication, 2016). Operating interest is charged in the budget at a rate of 5% on all operating costs.

Ownership Costs

Ownership costs are not tied directly to the level of crop production, and are incurred regardless of whether a crop is, or is not produced. These typically do not vary with output. They can be non-cash items such as depreciation or actual cash expenses such as rent. Ownership costs related to machinery and equipment have been discussed previously. Land rent was estimated as the average rate that might be paid for a potato crop in the area. Although a producer may own his or her farm ground, it is important to consider land rent as an expense in the budget because it is the opportunity cost that is incurred by growing the crop rather than renting it out to another grower or selling it.

The management fee was also considered an ownership cost for the potato enterprise. The management fee is the wage paid to the grower or manager for the management of the operation. It is important to include a management wage, even when the owner is the one providing the management, because it helps provide a more accurate assessment of the profitability of the enterprise, and accounts for the opportunity cost of the grower's time. In the model farm enterprise budget, the management fee is set to be equivalent to 5% of the operating costs (Patterson, 2013). It should be acknowledged that in practice, basing wages of management on actual expenses may not be a wise strategy, because it takes away some of the incentive for efficiency. This method was used simply to estimate a value that might be commensurate with the scale of the operation. There is much less variability in input costs than in revenue and therefore they provide a more stable basis for estimation of the management fee, for planning purposes.

Stochastic Factors

The deterministic budget is an important tool for a potato grower to prepare, but the reality is that they do not live in a world of fixed prices and conditions. Prices, weather, pest pressure, and other factors shift often in unpredictable ways. Potato producers face uncertainty and risk from many sources. Some sources of risk are more volatile than others. Stochastic simulation was used to account for variability and risk. Stochastic values in the budget are represented by statistical distributions that capture the range of probable values, rather than one fixed value. The stochastic factors in this analysis are total yield and potato price. These were selected not only for their volatility, but also for the weight of the effect that they can have on net returns of the enterprise. Simulation strength and dependability is dependent upon the reliability of the data from which distributions are defined. Defining these distributions in such a way that they accurately model the variability of the input is a critical part of building the model and setting up the simulation.

Price Data

Prices used in this budget may or may not reflect actual prices received by commercial potato growers, due to differences in contracts or terminal markets. Processor contracts are often complex, with discounts and premiums for tuber quality and condition. For simplicity in the model, a single price is received for all tubers excluding culls and shrinkage of the crop in storage.

Due to the extensive use of contracting, and differences in markets, reliable and recent price data for processing potatoes can be difficult to obtain. Price distributions were derived through a combination available historical data and expert opinion. Historical price data were accessed from the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). It is represented by the average price for processing potatoes in North Dakota for the marketing year for the years of 1994 to 2009 (USDA, 2016). Based on observed price distribution during this timeframe, the upward trend of nominal prices, expert opinion, and grower consensus, the range of possible prices and the most likely price was estimated. The *RiskTriang* function was used in the *@Risk7* software package (Palisade Corporation, 2016) to define the price within the stochastic budget with a minimum value of $7.50, a most likely value of $8.50 and a maximum value of $9.50 per cwt Figure 8 illustrates the randomly sampled values used in the simulation subject to the defined distribution.

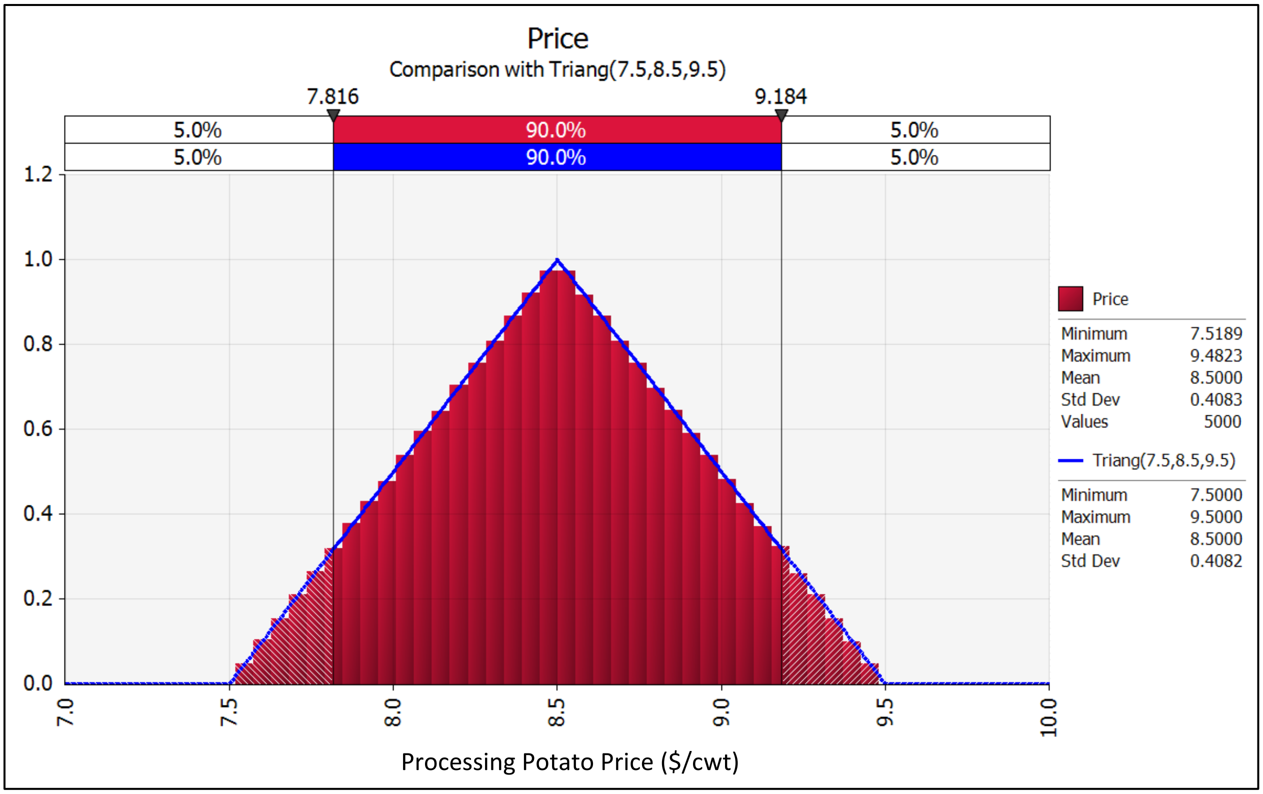

Figure 8. Values sampled in the stochastic budget simulation for the price of processing potatoes when grown in North Dakota, based on a triangular distribution.

Yield Data

Reliable yield data for potato are difficult to obtain because there is substantial variability in yields between cultivars, fields, producers, and regions of the state. Surveys of yield in North Dakota are often particularly clouded or distorted by the cultivars of potatoes grown under different production systems, such as non-irrigated or irrigated. The best yield data to use would be historical yields for the particular farm being simulated. However, since this information is not available for the model farm, yield was estimated, based on available historical data, expert opinion, and grower collaboration. Historical yield data was obtained from the NASS database for potato grown under irrigated conditions in North Dakota from 1994 to 2009 (USDA, 2016). The *RiskTriang* function in @Risk was used to define the range of yield values with a minimum yield of 375 cwt, a most likely value of 450 cwt, and the maximum value of 600 cwt per acre

(Figure 9). The randomly sampled yield values used in the simulation are depicted in Figure 8. This is the total yield of the field, given in cwt per acre, before culls and storage shrink are subtracted. It was estimated that, with fumigation, about 5% of the total yield would be culls, and thus unmarketable. In addition, another 10% would be lost to shrinkage during storage. This leaves approximately 85% of the total yield from the field that would be marketable. There is some variability in this breakdown of total yield, and additional work should be done to consider these percentages stochastically in the future. However, for the purpose of this analysis, only total yield is treated stochastically.

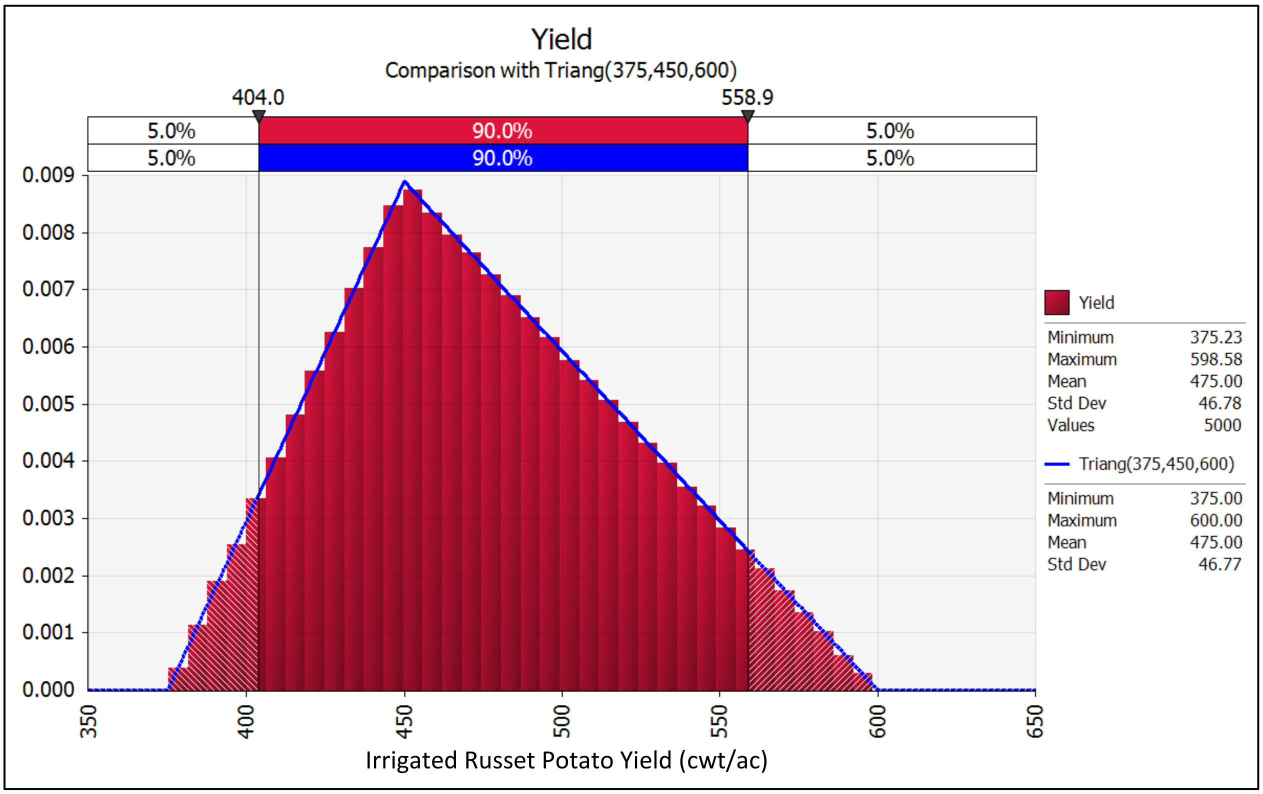

Figure 9. Randomly sampled yield values used in the stochastic budget simulation for irrigated russet potatoes in North Dakota, based on a triangular distribution.

Price-Yield Correlation

Historical price and yield data from the NASS database (USDA, 2016) were analyzed in *@Risk* using the *Batch Fit* function to assess the possible relationship between the two variables and derive an appropriate correlation matrix. The two were found to be highly correlated with a correlation coefficient of 0.788. The *RiskCorrmat* function was used in *@Risk* to correlate price and yield sampling. *RiskCorrmat* allows for multivariate correlation by referencing distribution functions to a correlation matrix (Palisade Corporation, 2016). This ensures that when price and yield values are sampled for inputs in the simulation they are not treated independently.

Simulation

The stochastic simulation model is specified as

$$NR_i = \tilde{P}_i \tilde{X}_i - VC - FC,$$

Where NR_i is the net return of simulation i, $\tilde{P}_i$ and $\tilde{X}_i$ are the simulated stochastic prices and yields, VC is the variable cost, and FC is the fixed cost. The stochastic factors were defined by their distribution functions, output for the simulation was specified as net returns above total cost per acre. *@Risk* was used to simulate the model with 5,000 iterations, yielding 5,000 unique net returns based on the random sampling of the stochastic inputs.

Results and Discussion

It is common for farming operations to prepare a *pro forma* budget when planning for the upcoming year. These budgets are nearly always deterministic in nature; however, there are a number of unknown and risky factors that make up some of the budget inputs. A deterministic budget only captures a single snapshot of a possible outcome, when in fact, there is a very wide range of possible outcomes due to many factors outside of the grower’s control. This variability is particularly profound in potato production. Initial preparation of a deterministic budget yielded a net return of $217 per acre, or $434,000 for the two thousand acre potato enterprise on the model farm. If a producer is not aware of the level of risk that exists in the enterprise he or she may develop a distorted view of their actual position. If decisions are made based largely on faith in the picture presented by the deterministic budget, without a means of quantifying and planning for the risk and level of deviation from the budget outcome, producers may face a financial catastrophe, or overlook a great opportunity.

Distribution of Simulated Net Returns

Most producers likely understand that there is a certain amount of risk and variability involved in growing and selling potatoes. The results obtained from the stochastic simulation aids understanding of the level of the risk involved. The simulation helps us understand the best and worse-case scenarios, and their probability of occurrence. The outputs (net returns) of each of the 5,000 iterations in the simulation were compiled into a histogram by *@Risk*, allowing for easy analysis of the results. Individual producers may have differing input costs, thus the shape of the output curve of the simulation is perhaps more important than the actual values derived. The shape and spread of the curve is determined by the stochastic inputs of price and yield. Input costs were treated as deterministic in this simulation, thus a producer with lower or higher input costs than the ones in this simulation may simply shift the curve to the left or the right by the amount of the difference in cost. Figure 10 shows the distribution of the simulated outcomes in a histogram. The mean net return in the simulation was $384 per acre. The standard deviation of the output was $430 per acre. In other words, net returns per acre will lie between -$47 and $813 per acre, approximately two years out of three (plus or minus one standard deviation). The range of possible returns that lie within one standard deviation of the mean varies by $1.72 million for the potato enterprise on the model farm. Standard deviation provides a useful value for understanding the level of variability, which is often closely associated with the level of risk (Palisade Corporation, 2016). The higher the standard deviation, the greater the variability that exists in the outcome. This can be a useful value to compare the enterprise with other investment opportunities, when discussing risk management. In the simulation, 20.4% of the iterations yielded a negative net return. The implication of this, is that in order for a potato producer to ensure their longevity in the enterprise, they must position the business such that it may withstand losing money approximately one year in five. Potato producers may feel optimistic since the distribution is skewed to the right, indicating that the potential for the highest returns is greater than the risk of the most substantial losses. Net returns observed in the simulation ranged from a loss of $551 per acre, or $1.10 million for the enterprise, to gains of $1,616 per acre, or $3.23 million for the entire enterprise.

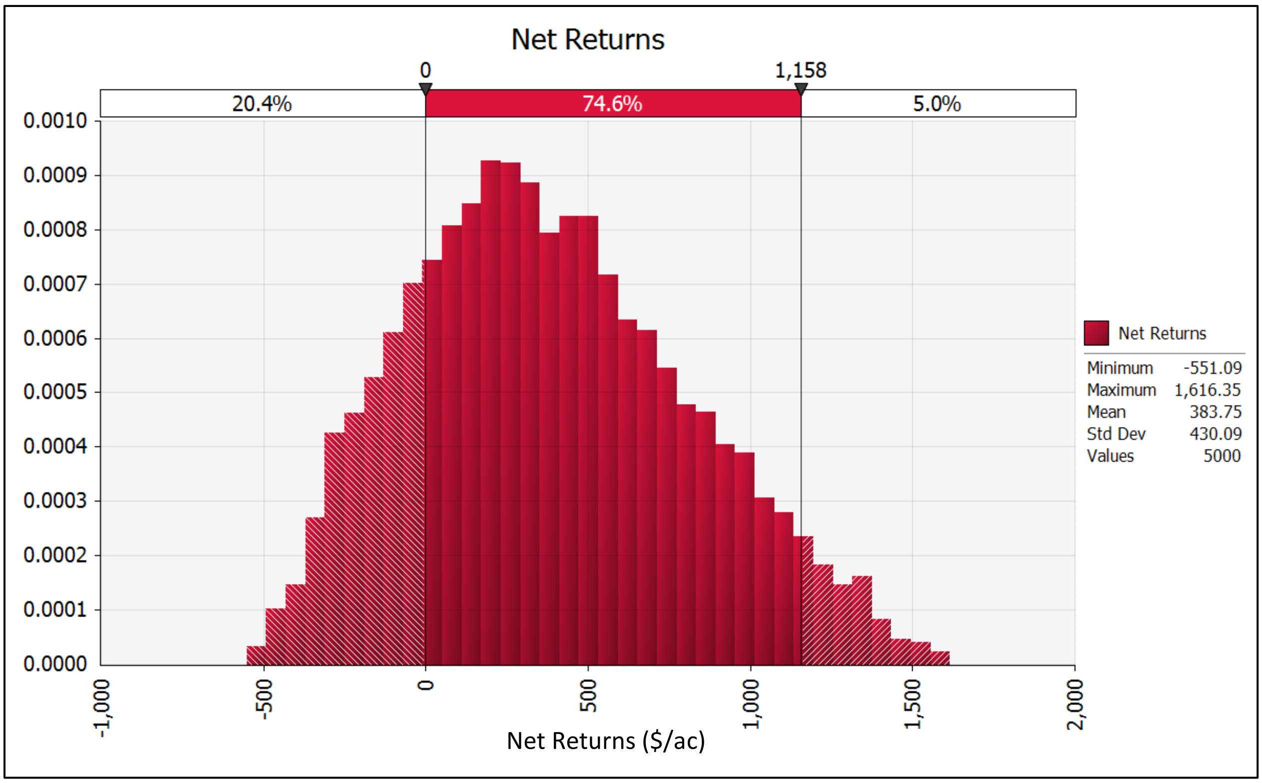

Figure 10. Probability density of simulated net returns, in dollars per acre, of irrigated russet potatoes grown in North Dakota for the processing market.

BestFit was used to fit a distribution to the output results for net returns; the beta general distribution was found to be the best according to the five goodness-of-fit statistics (Palisade Corporation, 2016). Often a farmer might expect his or her returns to be somewhat normally distributed. It appears that an assumption of normally distributed returns would actually overestimate potential losses, as seen in the left tail of the distribution (Figure 11). A producer acting on the assumption of normality, rather than on the basis of beta general distributed returns, is likely to take a slightly more risk averse position than intended. The normal distribution has slightly longer tails, particularly the lower tail, so the magnitude of potential losses may be slightly overestimated with normally distributed returns.

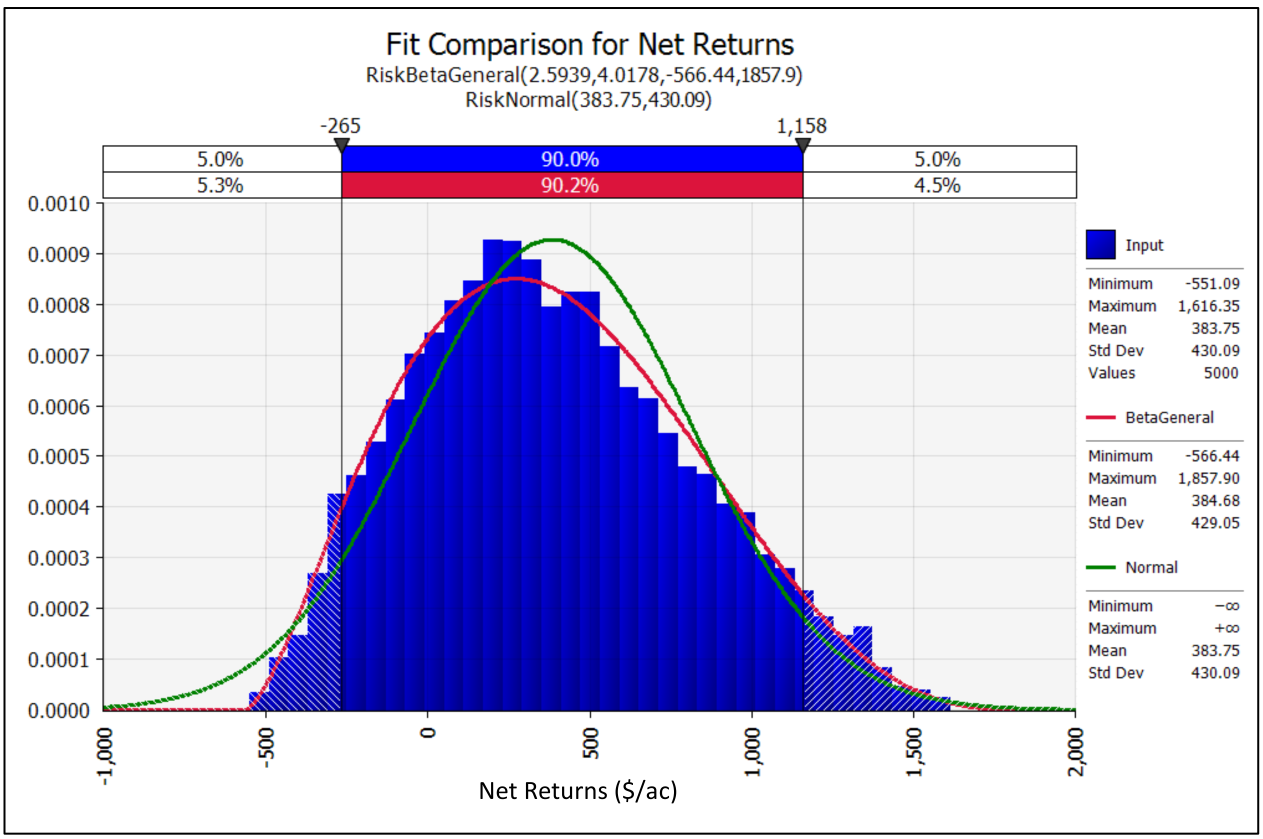

Figure 11. The best fit (beta general) and normal distributions, fit to the simulated net returns ($/ac) for irrigated russet potatoes grown in North Dakota.

A Wheat Comparison

In order to put the range of simulated potato returns into perspective, a similar, simplified analysis was conducted on hard red spring wheat. Wheat was chosen because it is another crop grown by the model farm and is typical in the crop rotation, with potatoes, in North Dakota. An enterprise budget for wheat was obtained from the North Dakota State University Extension Service (Swenson and Haugen, 2015). Price and yield were defined stochastically in the enterprise budget with normal distributions. Ten years of data was collected from the USDA (2016) NASS quick stats, in order to derive a mean and standard deviation for the price and yield of hard red spring wheat in ND.

Simulated net returns for wheat where much more tightly clustered around the mean than the net returns for potato (Figure 12). Wheat did not have the large chance of substantial losses that were present in potato; however, there was not the same possibility for large returns on the upper end either. Values representing the greatest 5% of losses in wheat are surpassed by potato 35% of the time. Conversely, values representing the most profitable 5% of years in wheat, were exceeded by potato nearly half of the time (45%). The difference in the volatility of net returns is apparent in the standard deviation. The standard deviation for potato net returns is $384.4 per acre, while the standard deviation for the net returns of wheat is $86.2 per acre. The value of one standard deviation is $149,100 greater for the 500 acre potato enterprise than for the 500 acre wheat enterprise.

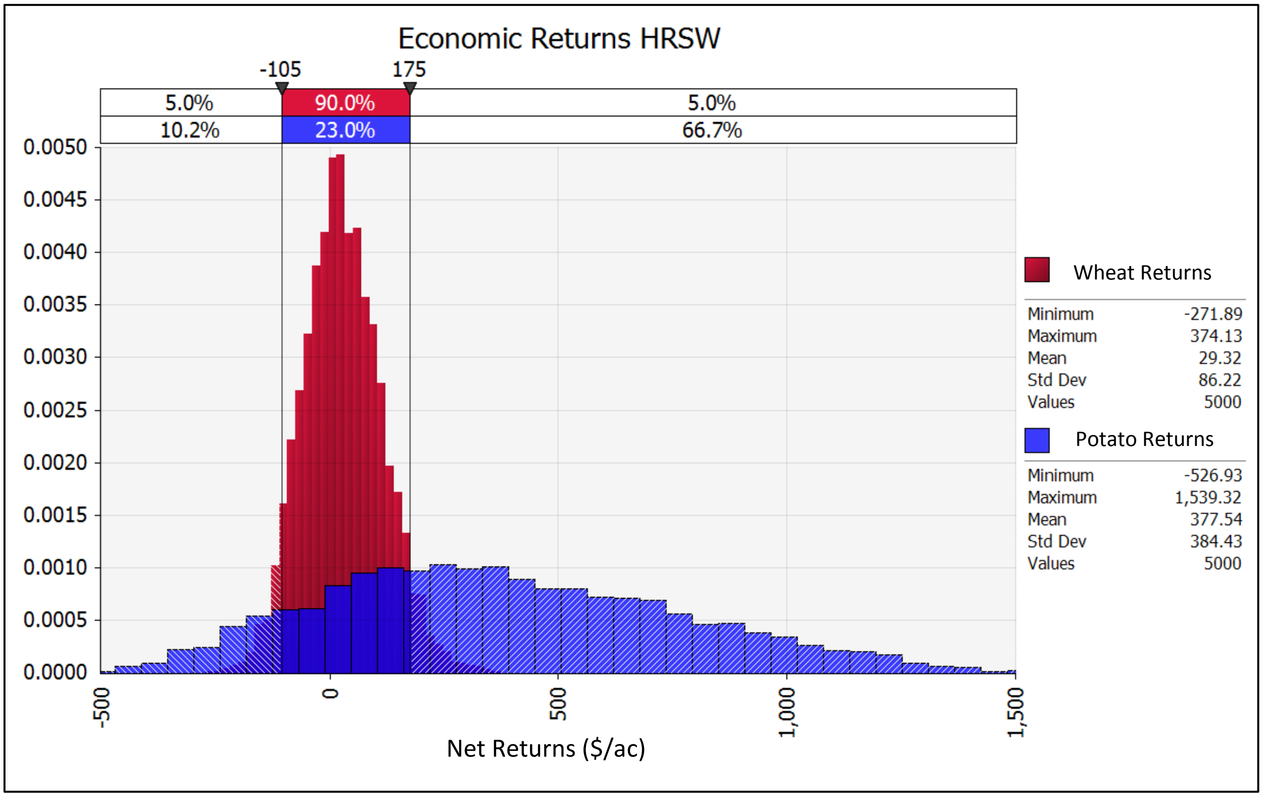

Figure 12. Overlaid probability density of net returns for hard red spring wheat and irrigated russet potato.

Magnitude of Input Effect on Net Returns

The tornado graph represents the magnitude of the effect of each of the stochastic inputs (price and yield) on net returns (Figure 13). The variability in price and yield, each have a nearly equivalent potential to affect the net returns of the potato enterprise; however, yield has a slightly larger ability to impact net returns than does yield, particularly on the upper end. This near-equivalence, allows the grower to pursue whatever risk management tools may be available knowing that management of either price or yield risk could efficiently decrease risk to the enterprise. There may be a slight relative advantage to controlling yield risk, but the difference is too small to say definitively. Price risk tools would be those things such as contracts or direct marketing, while yield risks could be managed with fumigation, scouting, efficient irrigation, and other crop health management strategies.

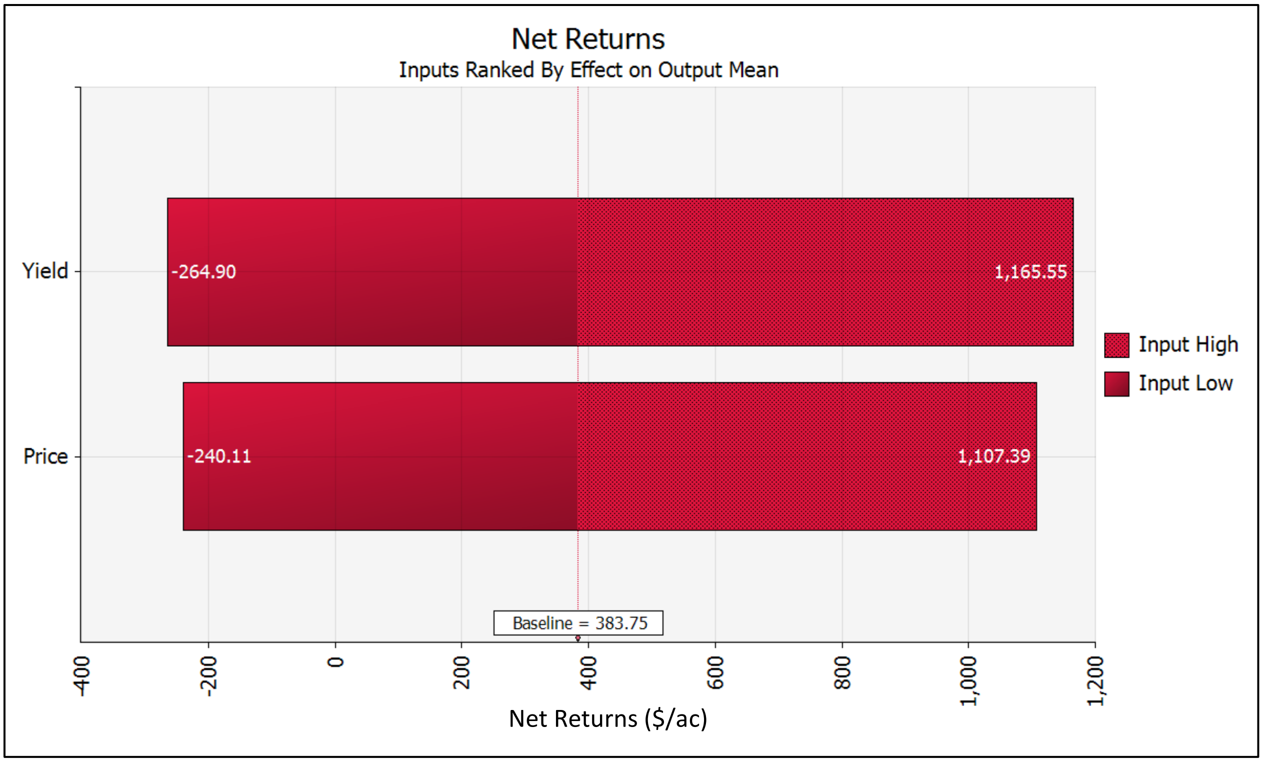

Figure 13. Tornado graph of the magnitude of the effect of each stochastic input (price and yield) on irrigated russet potato net returns ($/acre) in North Dakota.

Conclusion

It is a generally accepted notion that potato production is a risky enterprise; however, this is a somewhat subjective statement and does not provide any indication of the level of risk involved or how it may compare with another enterprise. A deterministic enterprise budget is an important starting point in seeking to understand what is at stake financially; however, it only provides a snapshot of one possible outcome. In reality, certain elements of the budget are variable and unpredictable, thus the returns expected are variable and unpredictable. Stochastic (or Monte Carlo) budgeting uses simulation to account for the variability, or risk, within the budget. Risky elements are considered as ranges of possible values rather than fixed amounts.

Price and yield are some of the most unpredictable, or risky, budget components with the greatest effect on net returns. Ranges of values for both price and yield were derived by a combination of historical data from North Dakota and expert opinion. The price for russet processing potatoes ranged from $7.50 to $9.50 per cwt. Yield values ranged from 375 to 600 cwt per acre.

Simulation of the irrigated potato enterprise on the model farm yielded a positive mean net return of $384 per acre, but also had a somewhat high standard deviation for net returns, making it difficult to predict positive returns consistently from year to year. Variability in price and yield have the potential to expose the enterprise to nearly equivalent levels of risk to net returns. The authors do not attempt to classify irrigated processing potato production as strictly low or high risk; however, these values provide a metric with which to measure the enterprise against others where resources might be devoted, to form a relative ranking of risk. Every decision maker has unique risk preferences based on their position and appetite for risk. Individual preferences for each party invested in the success of the enterprise should be understood and accounted for by the decision maker seeking to manage risk and maximize returns.

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FUMIGATION COST AND BREAK-EVEN ANALYSIS

Abstract

Soil fumigants are an important management tool in potato against certain yield limiting diseases; however, they are often among the highest single input costs for the potato crop. It is important for a producer to carefully evaluate the minimum benefit that must be realized in order justify incurring the cost of treatment. Fumigation break-even is a function of three variables, yield increase, increase in percent yield marketable, and market price. Yield increase required to break even has an inverse relationship to market price. Differences in the marketable yield rate due to fumigation, become less significant as yield increases due to fumigation become greater. The significance of differences in the marketable yield rate among products, decreases as total yield increases rise. Finally, the relative break even yield increase required will be lower for the scenario with the higher pre-fumigation yield potential, regardless of market price.

Introduction

Research indicates that significant total yield improvements, as well as improvements in the marketable yield percentage, may be gained with both metam sodium (Pasche et al., 2014) and chloropicrin fumigation (Hutchinson, 2005). Fumigation, if undertaken, may be among some of the largest single expenses to the potato enterprise. According to the NDSU model farm budget for irrigated russet potatoes, storage costs are the largest single expense, at nearly 18% of total operating costs, and fumigation is second, at approximately 16% of operating costs (see Table A7). The next greatest costs are fertilizer and seed, at 15% and 11% of operating costs, respectively (Table A7). A producer must carefully evaluate the benefits to yield and quality, gained from fumigation, in order to decide if they outweigh the high cost of fumigation. The objective of this chapter is to look at the combination of minimum criteria (break-even point), which must be met in order for fumigation to be economically feasible.

One of the most significant yield limiting factors faced by producers, especially in fields with a long history of potato production, is known as potato early dying (PED), also known as Verticillium wilt or early maturity wilt (Powelson and Rowe, 1993). This problem is of particular significance in the Red River Valley of North Dakota and Minnesota, and in Idaho where PED has developed slowly over many years (Powelson and Rowe, 1993).

Potato early dying is a common fungal disease of potato caused by one of two soil borne fungi, *Verticillium albo-atrum* or *Verticillium dahliae* (Wiggins 2002). Potato early dying thrives in warm temperatures. The optimal growth temperature for potatoes ranges from 65 to 68 °F (18 to 20 °C) while the optimal range for *V. dahlia* is 70 to 80 °F (21 to 27 °C) (Powelson and Rowe, 1993). Potato early dying causes premature senescence of the potato plant, four to six weeks earlier than normal (Kleinkopf et al. 2003). This can have a tremendous effect on a potato producer because it takes place during the important tuber bulking period of growth. During the bulking stage, Russet Burbank potatoes will increase yield by an average of 6.5 cwt/ac/day (729 kg/ha/day) (Kleinkopf et al. 2003). Premature senescence can lead to a significant reduction in tuber size and total marketable yield. Reductions in yield of moderately affected fields can be 10 to 15%; severely diseased fields can have yields reduced by 30 to 50% (Rowe and Powelson, 2002).

Verticillium wilt is arguably the most economically damaging disease to the potato industry in the United States when considering loss of yield and quality, and cost of control (Gudmestad et al. 2007). The recognition of this growing problem has been complicated in recent decades due to improved cultivars and cultural practices that have led to increased yields

(Powelson and Rowe, 1993). With these improvements the reduction in yield due to PED is less apparent, as overall yields have continued to rise. The true cost could be thought of as the potential for increased yield that has gone unrealized (Powelson and Rowe, 1993).

Management of PED

Cultivar selection is one of the standard recommendations for disease control and management in any crop. This is probably one of the best and most sustainable means of disease control; however, disease-resistant varieties often are not available in many crops, including potatoes. In fact, very few potato cultivars grown in the United States are more than moderately disease resistant (Secor and Gudmestad, 1999). Even when disease-resistant cultivars exist, they may not be suitable for the intended end use, such as chipping or baking (Secor and Gudmestad, 1999). Tillage practices are also a component of management of PED. Moldboard plowing helps redistribute the soil strata, burying the top few inches where the majority of the Verticillium propagules are found. A crop rotation allowing three or more years between potato crops also will help mitigate PED (Gudmestad et al., 2007). Fields cropped to potatoes with a rotation of two years or less between potato crops have been found to have two to four times greater Verticillium populations, than fields with longer rotations (Gudmestad et al., 2007).

The primary industry standard practice for controlling PED for the past several decades has been the application of metam-sodium (Rowe and Powelson, 2002). Metam sodium is a soil fumigant that is applied as a liquid and must volatize in order to permeate the soil profile (Gudmestad et al., 2007). Chloropicrin is another chemical used as a pre-plant soil fumigant to control soil-borne pests. It has been used agriculturally as a soil fumigant since 1920 (Pegg, 1984), but use in potatoes in the Upper Midwest is relatively new (A. P. Robinson, personal communication, 2016). The strong fungal control properties of chloropicrin are anticipated to improve tuber yield and quality by reducing *Verticillium* populations in the soil (Hutchinson, 2005). Chloropicrin was first used in strawberry production in California to control Verticillium wilt (Duniway, 2002). Mixtures of chloropicrin and methyl bromide have become standard applications for strawberries in California, and studies have shown yield increases of 44 to 85% as a result of fumigation (Duniway, 2002). Chloropicrin has also been used in nursery plants, peppers, tomatoes, and other crops. Historically, it has been shank applied or, more recently, as a drip application to the bed (Martin, 2003). The initial cost associated with chloropicrin treatment is higher, relative to that of metam sodium; one would need to realize a greater increase in yield or quality to adopt its use.

No matter what product or application method is employed, fumigation can be one of the single largest expenses in a potato enterprise budget. The decision to fumigate should be made carefully, considering all the costs and risks associated. Fumigation can be an effective tool for managing yield risk, but there is also the associated financial risk, that resources will be expended on treatment without realizing the full anticipated benefit. There are studies that look at fumigants and their effectiveness against their targets; however, there is little discussion of the cost effectiveness of these measures. The objective of this study was to identify the various combinations of yield and quality improvements that would need to be realized, in order for fumigation to be economically advantageous, depending on the market price of potatoes.

Materials and Methods

Fumigation Cost

Based on input from industry representatives, the custom application cost to inject metam sodium with deep shank tillage was estimated to be $60 per acre (Table A7). The rate of application used in this analysis was 50 gallons per acre (Amvac Chemical Corporation, 2015).

At a cost of $6 per gallon, the product cost is $300 per acre (Table A7). The total cost of fumigation for metam sodium is $360 per acre. The custom application rate for chloropicrin was estimated to be $35 per acre. The rate of application used was 100 pounds per acre (A. P. Robinson, personal communication, 2016). The cost is $4 per pound. The total fumigation cost of chloropicrin was $435 per acre.

Break-Even Discussion

This chapter does not attempt to establish which product yields superior net returns but rather to provide a simple means of analysis and comparison that producers may employ in understanding their own results and expectations. It demonstrates what variety of price and yield combinations would need to be expected in order to break-even with the additional cost of a fumigation. The examples shown are “what if” scenarios and not necessarily intended to represent actual results. This discussion focuses on two types of fumigation, but this concept could be applied to many of the production input decisions that are made by a potato producer.

There are three ways for a potato enterprise to increase revenue to pay for additional expenses incurred—a higher volume of tubers must be sold, marketable quality must improve, or tubers must be sold for more money. The three primary variables in consideration for this discussion are increase in total yield, increase in the marketable yield rate, and the price paid to the grower. The increase in yield required to break-even is a downward sloping curve with respect to increasing prices, as illustrated in Figure 14. This is an example of a metam sodium application with an assumption of a 7% increase in marketable yield, based on a 350 cwt per acre yield without fumigation. The fumigation break-even yield increase curve was generated with a range of price values inserted in the following formula:

$$\Delta Y = \frac{C - PY\Delta M}{P(\Delta M + M)}$$

Where: ΔY = Change in yield required to break even on the application
C = Cost of fumigation
P = Potato price
Y = Total yield without fumigation
M = Percent marketable tubers without fumigation
ΔM = Increase in percent marketable tubers due to fumigation

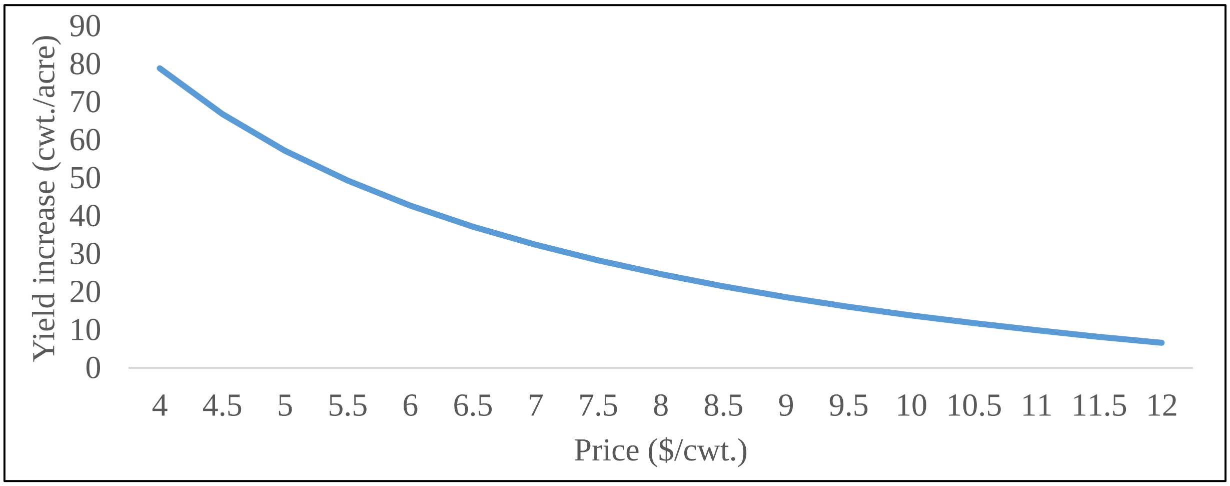

Figure 14. Example curve of yield increase needed to break even on metam sodium application. Based on a 350 cwt per acre total yield without fumigation, assumes 76% marketable yield rate without fumigation, and assumes a 7% increase in the marketable yield rate due to fumigation. Fumigation cost of $360 per acre

Considering the same information in a different way, Table A13 provides the minimum market conditions that would need to be met in order to break even on the fumigation based on the range of potential yield increases and improvements in the marketable yield rate realized due to fumigation. The table values were derived with the following formula:

$$P = \frac{C}{Y\Delta M + \Delta Y(M + \Delta M)}$$

Where: P = Potato price required to break even on fumigation

Greater increases in yield or marketable yield rate are necessary to offset the cost of fumigation when potato prices are low. Figure 15 shows a wide separation in break-even prices, among three marketable yield rate increases, when total yield increases are low; however, the separation narrows rapidly as the yield increase gained from fumigation grows. The implication of this is that if a grower were considering different fumigation products that were each expected to increase yield and marketable rate, he or she should carefully evaluate how these products might pay off. If the expectation of increased yield is somewhat low, then quality increases are heavily weighted in the decision process. However, if a greater yield increase is expected from both products, the impact of quality improvements becomes less significant.

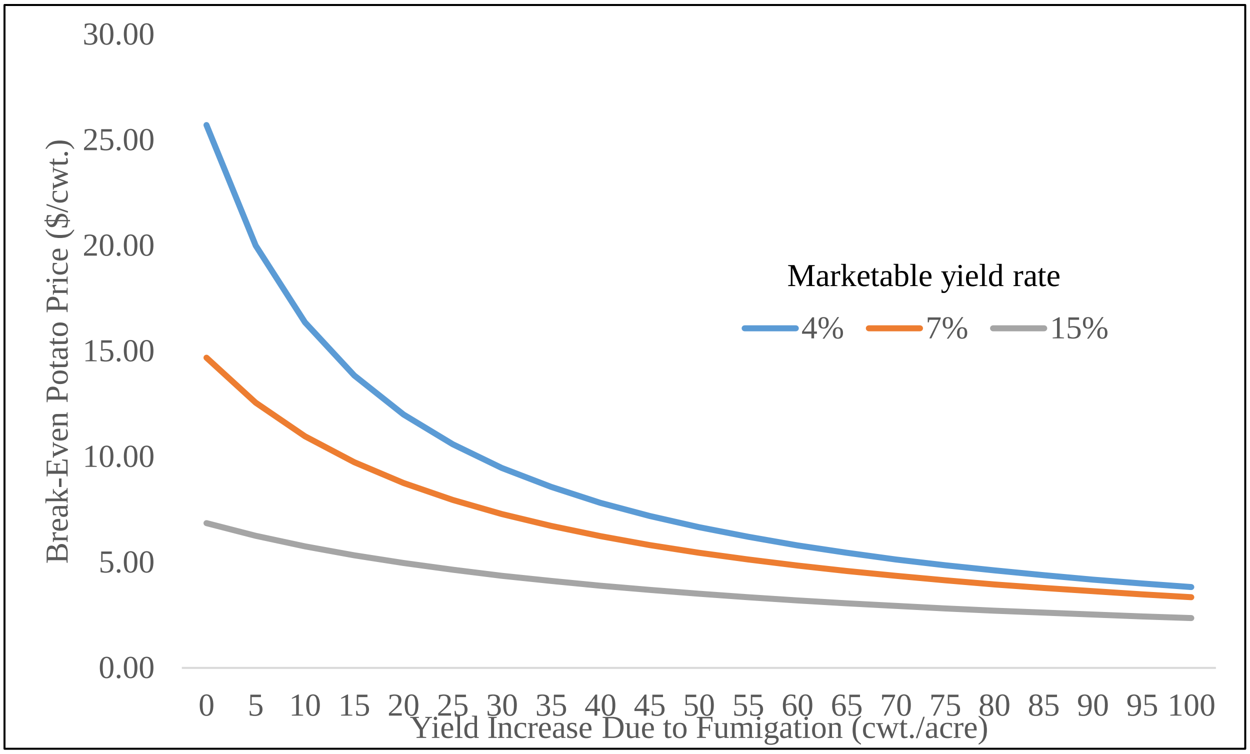

Figure 15. Potato price required to break even on fumigation depending on total yield increase realized for 3 different marketable yield rates. Based on 350 cwt per acre total yield without fumigation and assumes a 76% marketable yield rate without fumigation. Fumigation cost of $360 per acre.

To further illustrate the impact of expected prices, when faced with a decision between products of differing cost and differing results, consider the following example. Product A has a total cost, including application, of $360 per acre and promises a 4% increase in marketable yield, as well as a total yield increase. Product B has a higher cost of $435 per acre, but promises a 7% increase in marketable yield, as well as a total yield increase. Figure 16 shows the increase in total yield that would need to be attained for each of these two products to break even at a range of prices. If prices are expected to be low, the risk-averse preferred decision would be to employ the cheaper product, assuming both products increased total yield equally. However, as prices increase, these curves intersect, and the more expensive product B becomes more favorable, keeping all else constant.

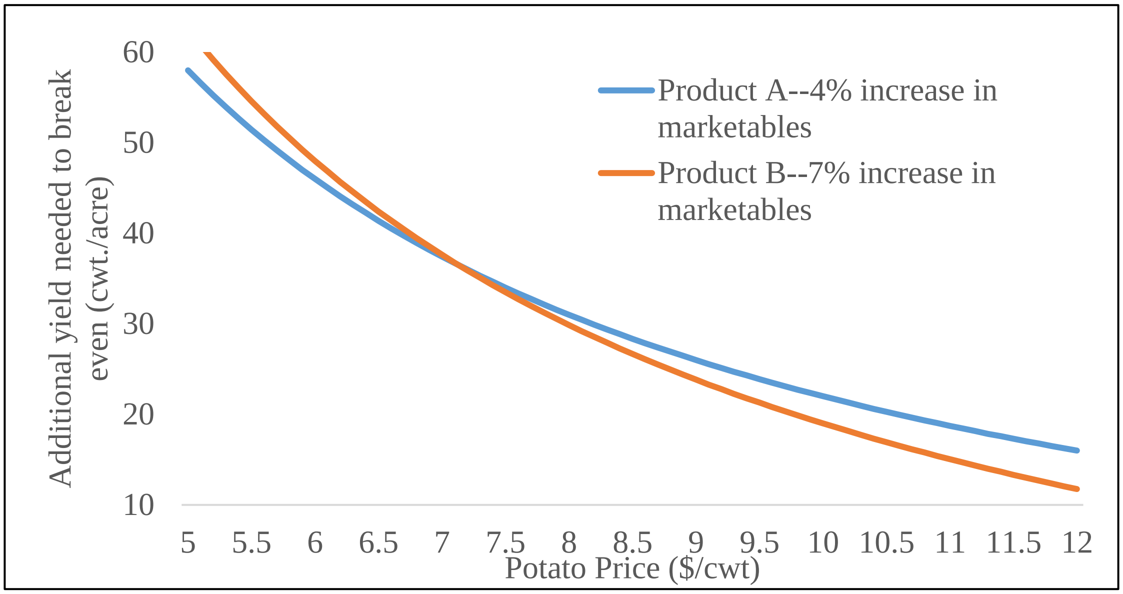

Figure 16. Yield increase needed to break even, subject to market price, for two different fumigant products with differing increases in marketable yield rate.

The level of yield a potato operation is able to achieve without fumigation is also an important factor to take into consideration when making the decision to fumigate. Consider two potato operations, one is growing irrigated russet potatoes with an average total yield of 350 cwt per acre, and the other is growing non-irrigated red potatoes with an average total yield of 190 cwt per acre. Assume that each enterprise has a 76% marketable rate without fumigation. The red potato grower will need to see a greater increase in yield to pay for the fumigation at any price level. This is because fumigation is a cost incurred by the acre. For the irrigated grower, the per-acre expense of fumigation is spread across a higher volume of yield, and thus the cost of fumigation per cwt sold is lower than that of the lower yielding non-irrigated grower. Figure 17 illustrates the yield increase break-even curve for each of these operations.

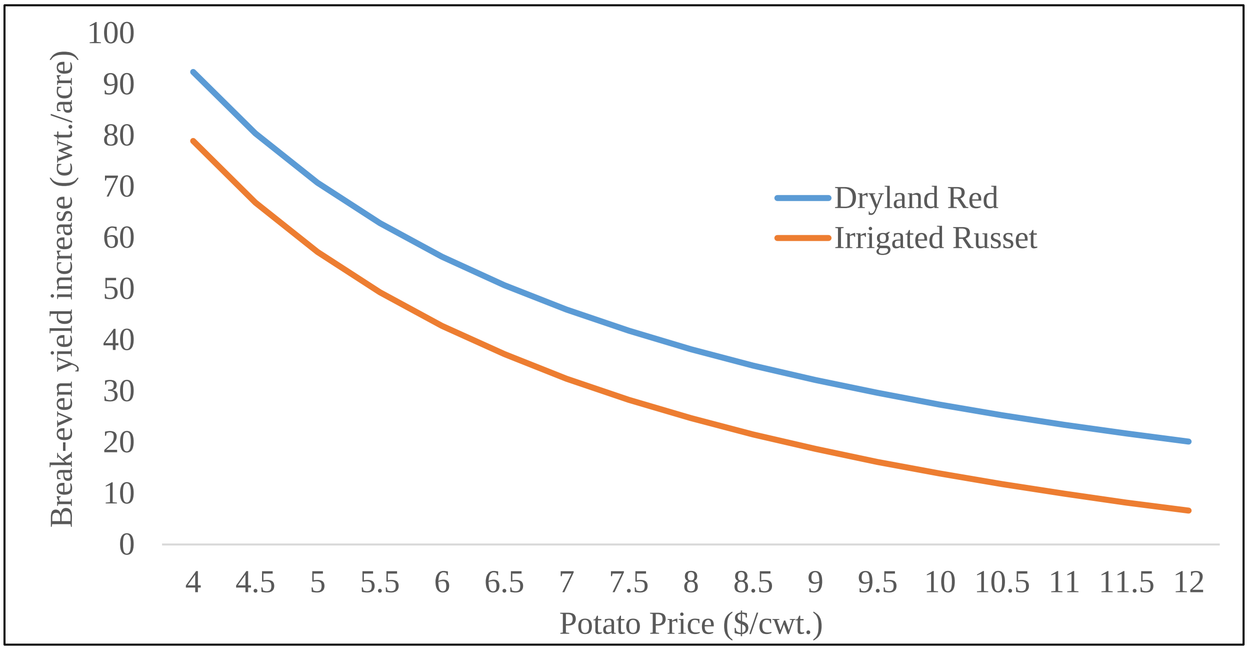

Figure 17. Yield increase needed to break even on fumigation with non-irrigated red potatoes and irrigated russet potatoes. Based on 350 cwt per acre yield for irrigated russets without fumigation, 190 cwt per acre yield for irrigated reds without fumigation, 76% marketable yield for each variety without fumigation, and 7% increase in marketable yield rate due to fumigation. Fumigation cost of $360 per acre.

Conclusion

If a potato grower chooses to fumigate, it may be one of the largest single costs incurred by the potato enterprise. Metam sodium fumigation of the model farm, incurred a cost of $360 per acre and chloropicrin fumigation incurred $435 per acre on the model farm. There are additional fumigant products available with their own beneficial claims. The rational and the framework presented here could easily be applied to other products or practices if one is able to quantify the benefit in terms of increased yield or quality.

The authors have not attempted to establish a superior product, but rather sought to lay out the conditions which would need to be met in order to break even on fumigation application. The three variables considered in this analysis were market price, increase in total yield, and increase in the marketable yield rate. As the market price of potatoes increases, the break-even curve is downward sloping, meaning that at higher market prices it takes less of an increase in yield or quality to pay for fumigation. While this may seem like an obvious observation, it is important for the farm to take the time to consider exactly where they fall on the curve. From a risk management perspective, a reasonable strategy would be to seek to minimize costs when prices are low, even if some yield is sacrificed, and to strive to maximize yields when prices are expected to be high, possibly to the point of incurring significant additional cost. There are times when it may not be possible to determine the best product to apply even when the increase in yield and quality are known. The break-even curves of two products of different costs, with different increases in quality may intersect, depending on the market price that will be received. A system with a higher before-fumigation yield will always have a lower break-even point than one with a lower yield, because the cost of application is spread out among more units of sale.

In a real-world application there are several combinations of variables that interact with one another in different ways to affect the outcome of a particular decision. One must continually evaluate these considerations as they change, based on conditions and market expectations.

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APPENDIX

Table A1. NDSU model farm budget for non-irrigated red potato production.

		Quantity per Acre	Unit	Price per Unit	Value or cost/acre		Value or cost/cwt
GROSS RETURNS				--------------------$--------------------			
Total Yield		186	cwt			**2709.7**	**19.22**
A (marketable)	75	106	cwt	16.31	1724.4		
B	20	28	cwt	23.96	675.48		
C	5%	7	cwt	43.96	309.85		
Culls	12						
Shrinkage	12						
% Marketable	76						
TOTAL GROSS RETURNS						**2709.7**	**19.22**
OPERATING INPUTS							
Seed						**324.00**	**2.30**
G3 Red Norland Seed		24	cwt	12.00	288.00		
Seed Freight		24	cwt	1.00	24.00		
Seed Cutting		24	cwt	0.50	12.00		
Fertilizer		*Refer to Table A2*				**172.01**	**1.22**
Pesticides						**170.54**	**1.21**
Herbicide		*Refer to Table A3*			49.22		
Insecticide		*for an itemized breakdown*			3.74		
Fungicide		*of pesticide costs*			85.93		
Desiccant					31.65		
Custom						**81.50**	**0.58**
Custom Fertilize		1	app	6.50	6.50		
Consultants/Soil Testing		1	acre	10.00	10.00		
Custom Spray		10	spray	6.50	65.00		
Machinery						**150.62**	**1.07**
Fuel--Gas		3.1	gal	2.40	7.43		
Fuel--Red Diesel		13.7	gal	2.00	27.42		
Fuel--Road Diesel		6.2	gal	2.60	16.12		
Lube		*Refer to Table A5 for*			7.65		
Machinery Repair		*itemized lube and repair*			92.00		

Table A1. NDSU model farm budget for non-irrigated red potato production (continued).

	Quantity per Acre	Unit	Price per Unit		Value or cost/acre	Value or cost/cwt
OPERATING INPUTS Continued			--------------------$--------------------			
Labor					**93.60**	**0.66**
Equipment Operator	1.34	hr	22.00	29.44		
Truck Driver	2.84	hr	17.00	48.26		
General Farm Labor	1.14	hr	14.00	15.91		
Storage and Washing					**685.76**	**4.86**
Storage	185.5	cwt	0.90	166.9		
Wash Plant Charge	141	cwt	3.68	518.8		
Other					**222.48**	**1.58**
Crop Insurance	1	acre	120.00	120.0		
Potato Fees and	141	cwt	0.09	11.98		
Operating Interest: 5%				90.50		
TOTAL OPERATING COSTS					**1900.51**	**13.48**
Net Returns Above Operating Expenses per acre					809.25	
OWNERSHIP COSTS						
Tractors & Equipment Insurance and housing					13.18	**0.09**
Tractors & Equipment Deprec. & Interest					198.48	**1.41**
Land Rent					250.00	**1.77**
General Overhead					47.51	**0.34**
Management Fee					95.03	**0.67**
TOTAL OWNERSHIP COSTS					**604.20**	**4.29**
TOTAL COSTS					**2504.70**	**17.77**
NET RETURNS ABOVE TOTAL COST					**205.05**	**1.45**

Table A2. Fertility plan and cost of product for non-irrigated red potato production.

Product	Rate/ac.	App. Unit	Price ($/unit)	Sale Unit	Cost/acre ($)
10-34-0	25.0	gal	516	ton	75.14
Urea	171.0	lb	365	ton	31.21
MAP	120.0	lb	512	ton	30.72
KCL	125.0	lb	375	ton	23.44
AMS	42.0	lb	338	ton	7.10
Zn	5.5	lb	0.8	lb	4.40
Total Fertilizer Cost					**172.01**

Table A3. Pesticide application rates and cost of product for non-irrigated red potato production.

	Product	Rate/ac.	app. Unit	Price $/unit	sale Unit	Cost/acre ($)
Herbicide						
	Pre-emergent					
	Dual Magnum	1.5	pt	120	gal	22.50
	Prowl H2O	2.7	pt	50	gal	16.72
	Metribuzin	0.5	lb	20	lb	10.00
	Post-emergent					
	MH-30	1	gal	15	gal	15.00
	2,4-D	2.3	oz	28	gal	0.50
	2,4-D	2.3	oz	28	gal	0.50
	Total herbicide cost					49.22
Insecticide						
	Admire Pro	8.7	oz	55	gal	3.74
	Total insecticide cost					3.74
Fungicide						
	Seed					
	Emesto Silver	0.31	oz/cwt	325	gal	18.89
	Quadris	8.7	oz	190	gal	12.91
	Foliar					
	Echo 720	0.75	pt	30	gal	2.81
	Koverall	2	lb	3	lb	6.00
	Echo 720	1.5	pt	30	gal	5.63
	Koverall	2	lb	3	lb	6.00
	Luna Tranquility	11.2	oz	385	gal	33.69
	Total fungicide cost					85.93
Desiccant						
	Reglone	1	pt	105	gal	13.13
	R11 adjuvant	0.8	pt	27	gal	2.70
	Reglone	1	pt	105	gal	13.13
	R11 adjuvant	0.8	pt	27	gal	2.70
	Total desiccant cost					31.65

Table A4. Whole farm equipment overhead costs for non-irrigated red potato production.

				Capital Recovery		Insurance & Housing		Potato
Equipment	New cost	Years life	Salvage value	Farm total	Potato portion	Farm total	Potato portion	overhead per acre
Pickup 1 - 3/4 ton	45,000	5	14,000	7,861	3,144	295	118	6.52
Pickup 2 - 3/4 ton	45,000	5	14,000	7,861	3,144	295	118	6.52
Pickup 3 - 3/4 ton	45,000	5	14,000	7,861	3,144	295	118	6.52
Tractor 1 - 260hp MFWD	301,000	12	84,280	28,703	12,757	1,926	856	27.23
Tractor 2 - 350hp track	360,000	12	100,800	34,330	13,732	2,304	922	29.31
Tractor 3 - 225hp MFWD	225,000	12	63,000	21,456	10,728	1,440	720	22.90
Potato Planter 6-Row	75,000	25	-	5,325	5,325	375	375	11.40
Potato Hiller 6-Row	25,000	30	-	1,625	1,625	125	125	3.50
Potato Harvester 4-Row	160,000	20	15,000	12,350	12,350	875	875	26.45
Harvester #2 - 4-Row	160,000	20	15,000	12,350	12,350	875	875	26.45
Truck 1 - Tandem axle	105,000	20	7,000	8,190	4,095	560	280	8.75
Truck 2 - Tandem axle	105,000	20	7,000	8,190	4,095	560	280	8.75
Truck 3 - Tandem axle	105,000	20	7,000	8,190	4,095	560	280	8.75
Truck 4 - Tandem axle	105,000	20	7,000	8,190	4,095	560	280	8.75
Truck 5 - Tandem axle	105,000	20	7,000	8,190	4,095	560	280	8.75
Truck 6 - Tandem axle	105,000	20	7,000	8,190	4,095	560	280	8.75
Truck 7 - Tandem axle	105,000	20	7,000	8,190	4,095	560	280	8.75
Truck 8 - Tandem axle	105,000	20	7,000	8,190	4,095	560	280	8.75
Chisel plow - 37ft	49,000	20	7,840	3,685	921	284	71	1.98
Tandem Disk - 30ft fold	54,000	20	8,640	4,061	1,015	313	78	2.19
Dump truck	30,000	20	2,000	2,340	2,340	160	160	5.00
Fuel Truck	50,000	20	3,000	3,910	1,564	265	106	3.34
Service Truck	40,000	20	3,000	3,110	1,244	215	86	2.66
Totals	2,504,000		400,560	222,348	118,144	14,523	7,843	251.98
84% of New Cost*	2,103,360		336,470	186,772	99,241	12,199	6,588	211.66

*Used to reflect a mix of new and used equipment (Patterson, 2013)

Table A5. Whole farm equipment operating costs for non-irrigated potatoes in dollars.

	Repairs		Fuel		Lube		Potato
Equipment	Farm total	Potato portion	Farm total	Potato portion	Farm total	Potato portion	operating cost per acre
Pickup 1 - 3/4 ton	1,620	648	3,000	1,200	450	180	4.06
Pickup 2 - 3/4 ton	1,620	648	3,000	1,200	450	180	4.06
Pickup 3 - 3/4 ton	1,620	648	3,000	1,200	450	180	4.06
Tractor 1 - 260hp MFWD	1,254	557	7,354	3,269	1,103	490	8.63
Tractor 2 - 350hp track	3,300	1,320	15,033	6,013	2,255	902	16.47
Tractor 3 - 225hp MFWD	1,500	750	8,856	4,428	1,328	664	11.68
Potato Planter 6-Row*	1,740	1,740					3.48
Potato Hiller 6-Row*	533	533					1.07
Potato Harvester 4-Row*	17,000	17,000					34.00
Harvester #2 - 4-Row*	17,000	17,000					34.00
Truck 1 - Tandem axle	945	473	1,872	936	281	140	3.10
Truck 2 - Tandem axle	945	473	1,872	936	281	140	3.10
Truck 3 - Tandem axle	945	473	1,872	936	281	140	3.10
Truck 4 - Tandem axle	945	473	1,872	936	281	140	3.10
Truck 5 - Tandem axle	945	473	1,872	936	281	140	3.10
Truck 6 - Tandem axle	945	473	1,872	936	281	140	3.10
Truck 7 - Tandem axle	945	473	1,872	936	281	140	3.10
Truck 8 - Tandem axle	945	473	1,872	936	281	140	3.10
Chisel plow - 37ft*	1,568	392					0.78
Tandem Disk - 30ft fold*	1,566	392					0.78
Dump truck	270	270	416	416	62	62	1.50
Fuel Truck	450	180	390	156	59	23	0.72
Service Truck	360	144	288	115	43	17	0.55
Totals	58,962	46,002	56,314	25,485	8,447	3,823	150.62

*No fuel or lube costs are allocated to these implements because it is accounted for with the tractor to which it is attached.

Table A6. Equipment usage and labor for non-irrigated red potato production.

Equipment	Total annual hrs.	Potato hrs.	Labor hrs/acre potato*
Tractor 1 - 260hp MFWD	321	143	
Tractor 2 - 350hp track	488	195	
Tractor 3 - 225hp MFWD	447	224	
Potato Planter 6-Row	139	139	0.32
Potato Hiller 6-Row	85	85	0.19
Potato Harvester 4-Row	143	143	0.33
Harvester #2 - 4-Row	143	143	0.33
Truck 1 - Tandem axle	309	154	0.35
Truck 2 - Tandem axle	309	154	0.35
Truck 3 - Tandem axle	309	154	0.35
Truck 4 - Tandem axle	309	154	0.35
Truck 5 - Tandem axle	309	154	0.35
Truck 6 - Tandem axle	309	154	0.35
Truck 7 - Tandem axle	309	154	0.35
Truck 8 - Tandem axle	309	154	0.35
Chisel plow - 37ft	95	24	0.05
Tandem Disk - 30ft fold	114	29	0.07
Dump Truck	20	20	0.05
Fuel Truck	50	20	0.05
Service Truck	50	20	0.05
Total equipment labor hours			4.27

*Labor hours are calculated as 1.15 times machine hours.
*No labor hours are assigned to tractors because labor is tied to the implement.

Table A7. NDSU model farm budget for irrigated russet potato production.

		Quantity per Acre	Unit	Price per Unit		Value or cost/acre	Value or cost/cwt
GROSS RETURNS				--------------------$--------------------			
Total Yield		450	cwt	8.50		**3251.25**	**8.50**
Culls	5%						
Shrinkage	10%						
% Marketable	85%						
TOTAL GROSS RETURNS						**3251.25**	**8.50**
OPERATING INPUTS							
Seed						**256.50**	**0.67**
G3 Russet Burbank Seed		19	cwt	12.00	228.00		
Seed Freight		19	cwt	1.00	19.00		
Seed Cutting		19	cwt	0.50	9.50		
Fumigation						**360.00**	**0.94**
Metam sodium		50	gal.	6.00	300.00		
Custom Shank Fumigation		1	app.	60.00	60.00		
Fertilizer		*Refer to Table A8*				**345.93**	**0.90**
Pesticides						**214.95**	**0.56**
Herbicide		*Refer to Table A9*			49.22		
Insecticide		*for itemized breakdown*			3.74		
Fungicide		*of pesticide costs*			130.34		
Desiccant					31.65		
Custom						**124.00**	**0.32**
Custom Fertilize		1	app.	6.50	6.50		
Consultants/Soil Testing		1	acre	10.00	10.00		
Custom Aerial Application		11	spray	8.00	88.00		
Custom Ground Spray		3	spray	6.50	19.50		
Machinery						**100.30**	**0.26**
Fuel--Gas		2.53	gal.	2.40	6.07		
Fuel--Red Diesel		11.96	gal.	2.00	23.92		
Fuel--Road Diesel		7.81	gal.	2.60	20.31		
Lube		*Refer to Table A11 for*			6.84		
Machinery Repair		*itemized lube and repair*			73.15		
Irrigation						**110.00**	**0.51**
Power & Water Permit		20	ac-in	5.00	100.00		
Irrigation Repairs		20	ac-in	0.50	10.00		

Table A7. NDSU model farm budget for irrigated russet potato production (continued).

	Quantity per Acre	Unit	Price per Unit		Value or cost/acre	Value or cost/cwt
OPERATING INPUTS Continued			--------------------$--------------------			
Labor					**97.43**	**0.25**
Equipment Operator	1.3	hr.	22.00	28.60		
Truck Driver	2.03	hr.	17.00	34.51		
General Farm Labor	0.88	hr.	14.00	12.32		
Irrigation Labor	1	hr.	22.00	22.00		
Storage					**405.00**	**1.06**
Storage	450	cwt	0.90	405.0		
Other					**260.84**	**0.68**
Crop Insurance	1	acre	120.00	120.0		
Fees and Assessments	382.5	cwt	0.085	32.51		
Operating Interest: 5%				108.3		
TOTAL OPERATING COSTS					**2274.95**	**5.95**
Net Returns Above Operating Expenses per acre				976.3		
OWNERSHIP COSTS						
Tractors & Equipment Insurance and housing					11.68	0.03
Tractors & Equipment Deprec. & Interest					175.89	0.46
Land Rent					400.00	1.05
General Overhead					56.87	0.15
Management Fee					113.75	0.30
TOTAL OWNERSHIP COSTS					**758.19**	**1.98**
TOTAL COSTS					**3033.14**	**7.93**
NET RETURNS ABOVE TOTAL COST					**218.11**	**0.57**

Table A8. Fertility plan and cost of product for irrigated russet potato production.

Product	Rate/ac.	App. Unit	Price ($/unit)	Sale Unit	Cost/acre ($)
Urea	87	lb.	365	ton	15.88
10-34-0	25	gal.	516	ton	75.14
ESN	409	lb.	765	ton	156.44
MAP	120	lb.	512	ton	30.72
KCL	300	lb.	375	ton	56.25
AMS	42	lb.	338	ton	7.10
Zn	5.5	lb.	0.8	lb	4.40
Total Fertilizer Cost					**345.93**

Table A9. Pesticide application rates and cost of product for irrigated russet potato production.

	Product	Rate/ac.	app Unit	Price ($/unit)	sale Unit	Cost/acre ($)
Herbicide						
	Pre-emergent					
	Dual Magnum	1.5	pt	120	gal	22.50
	Prowl H2O	2.7	pt	50	gal	16.72
	Metribuzin	0.5	lb	20	lb	10.00
	Post-emergent					
	MH-30	1	gal	15	gal	15.00
	Matrix	1	oz	20	oz	20.00
	Total herbicide cost					49.22
Insecticide						
	Admire Pro	8.7	oz	55	gal	3.74
	Total insecticide cost					3.74
Fungicide						
	Seed					
	Emesto Silver	0.31	oz/cwt	325	gal	14.96
	Quadris	8.7	oz	190	gal	12.91
	Foliar					
	Echo 720	0.75	pt	30	gal	2.81
	Koverall	2	lb	3	lb	6.00
	Echo 720	1.5	pt	30	gal	5.63
	Koverall	2	lb	3	lb	6.00
	Echo 720	1.5	pt	30	gal	5.63
	Koverall	2	lb	3	lb	6.00
	Revus Top	7	oz	285	gal	15.59
	Luna Tranquility	11.2	oz	385	gal	33.69
	Omega 500F	5.5	fl oz	400	gal	17.19
	AgriTin	5	fl oz	101	gal	3.95
	Total fungicide cost					130.34
Desiccant						
	Reglone	1	pt	105	gal	13.13
	R11 adjuvant	0.8	pt	27	gal	2.70
	Reglone	1	pt	105	gal	13.13
	R11 adjuvant	0.8	pt	27	gal	2.70
	Total desiccant cost					31.65

Table A10. Whole farm equipment overhead costs for irrigated russet potatoes in dollars.

				Cash Overhead		Insurance & Housing		Potato
Equipment	New cost	Years life	Salvage value	Farm total	Potato portion	Farm total	Potato portion	overhead per acre
Pickup 1 - 3/4 ton	45,000	5	14,000	7,861	3,931	295	148	2.04
Pickup 2 - 3/4 ton	45,000	5	14,000	7,861	3,931	295	148	2.04
Pickup 3 - 3/4 ton	45,000	5	14,000	7,861	3,931	295	148	2.04
Pickup 4 - 3/4 ton	45,000	5	14,000	7,861	3,931	295	148	2.04
Pickup 5 - 3/4 ton	45,000	5	14,000	7,861	3,931	295	148	2.04
Pickup 6 - 3/4 ton	45,000	5	14,000	7,861	3,931	295	148	2.04
Pickup 7 - 3/4 ton	45,000	5	14,000	7,861	3,931	295	148	2.04
Pickup 8 - 3/4 ton	45,000	5	14,000	7,861	3,931	295	148	2.04
Tractor 1 - 350hp track	360,000	12	100,800	34,330	6,866	2,304	461	3.66
Tractor 2 - 350hp track	360,000	12	100,800	34,330	6,866	2,304	461	3.66
Tractor 3 - 260hp MFWD	301,000	12	84,280	28,703	22,963	1,926	1,541	12.25
Tractor 4 - 260hp MFWD	301,000	12	84,280	28,703	11,481	1,926	771	6.13
Tractor 5 - 260hp MFWD	301,000	12	84,280	28,703	11,481	1,926	771	6.13
Tractor 6 - 225hp MFWD	225,000	12	63,000	21,456	21,456	1,440	1,440	11.45
Tractor 7 - 225hp MFWD	225,000	12	63,000	21,456	21,456	1,440	1,440	11.45
Tractor 8 - 225hp MFWD	225,000	12	63,000	21,456	21,456	1,440	1,440	11.45
Potato Planter 6-Row	75,000	25	-	5,325	5,325	375	375	2.85
Planter 2 6-Row	75,000	25	-	5,325	5,325	375	375	2.85
Planter 3 6-Row	75,000	25	-	5,325	5,325	375	375	2.85
Planter 4 6-Row	75,000	25	-	5,325	5,325	375	375	2.85
Potato hiller 6-Row	25,000	30	-	1,625	1,625	125	125	0.88
Hiller 2 6-Row	25,000	30	-	1,625	1,625	125	125	0.88
Hiller 3 6-Row	25,000	30	-	1,625	1,625	125	125	0.88
Potato harvester 4-Row	160,000	20	15,000	12,350	12,350	875	875	6.61

Table A10. Whole farm equipment overhead costs for irrigated russet potatoes in dollars (continued).

Equipment	New cost	Years life	Salvage value	Cash Overhead: Farm total	Cash Overhead: Potato portion	Insurance & Housing: Farm total	Insurance & Housing: Potato portion	Potato overhead per acre
Harvester 2 4-Row	160,000	20	15,000	12,350	12,350	875	875	6.61
Harvester 3 4-Row	160,000	20	15,000	12,350	12,350	875	875	6.61
Harvester 4 4-Row	160,000	20	15,000	12,350	12,350	875	875	6.61
Harvester 5 4-Row	160,000	20	15,000	12,350	12,350	875	875	6.61
Harvester 6 4-Row	160,000	20	15,000	12,350	12,350	875	875	6.61
Truck 1 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 2 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 3 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 4 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 5 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 6 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 7 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 8 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 9 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 10 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 11 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 12 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 13 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 14 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 15 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 16 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 17 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38
Truck 18 - Tandem axle	105,000	20	7,000	8,190	8,190	560	560	4.38

Table A10. Whole farm equipment overhead costs for irrigated russet potatoes in dollars (continued).

Equipment	New cost	Years life	Salvage value	Cash Overhead: Farm total	Cash Overhead: Potato portion	Insurance & Housing: Farm total	Insurance & Housing: Potato portion	Potato overhead per acre
Chisel plow - 37ft	49,000	12	7,840	3,685	921	284	71	0.50
Chisel plow 2 - 37ft	49,000	12	7,840	3,685	921	284	71	0.50
Tandem Disk - 30ft fold	54,000	10	8,640	4,061	1,015	313	78	0.55
Tandem Disk 2 - 30ft fold	54,000	10	8,640	4,061	1,015	313	78	0.55
Dump Truck 1	30,000	20	2,000	2,340	2,340	160	160	1.25
Dump Truck 2	30,000	20	2,000	2,340	2,340	160	160	1.25
Fuel Truck 1	60,000	20	3,000	4,710	2,355	315	158	1.26
Fuel Truck 2	60,000	20	3,000	4,710	2,355	315	158	1.26
Service Truck	60,000	20	3,000	4,710	2,355	315	158	1.26
Totals	6,329,000		1,017,400	564,021	418,782	36,732	27,800	223.29
84% of New Cost*	5,316,360		854,616	473,778	351,777	30,855	23,352	187.56

*Used to reflect a mix of new and used equipment (Patterson, 2013)

Table A11. Whole farm equipment operating costs for irrigated russet potatoes in dollars.

	Repairs		Fuel		Lube		Potato operating cost per acre
Equipment	Farm total	Potato portion	Farm total	Potato portion	Farm total	Potato portion	
Pickup 1 - 3/4 ton	1,620	810	3,000	1,500	450	225	1.27
Pickup 2 - 3/4 ton	1,620	810	3,000	1,500	450	225	1.27
Pickup 3 - 3/4 ton	1,620	810	3,000	1,500	450	225	1.27
Pickup 4 - 3/4 ton	1,620	810	3,000	1,500	450	225	1.27
Pickup 5 - 3/4 ton	1,620	810	3,000	1,500	450	225	1.27
Pickup 6 - 3/4 ton	1,620	810	3,000	1,500	450	225	1.27
Pickup 7 - 3/4 ton	1,620	810	3,000	1,500	450	225	1.27
Pickup 8 - 3/4 ton	1,620	810	3,000	1,500	450	225	1.27
Tractor 1 - 350hp track	3,300	660	16,133	3,227	2,420	484	2.19
Tractor 2 - 350hp track	3,300	660	16,133	3,227	2,420	484	2.19
Tractor 3 - 260hp MFWD	1,254	1,003	9,164	7,331	1,375	1,100	4.72
Tractor 4 - 260hp MFWD	1,254	502	10,400	4,160	1,560	624	2.64
Tractor 5 - 260hp MFWD	1,254	502	10,400	4,160	1,560	624	2.64
Tractor 6 - 225hp MFWD	1,500	1,500	8,582	8,582	1,287	1,287	5.68
Tractor 7 - 225hp MFWD	1,500	1,500	8,582	8,582	1,287	1,287	5.68
Tractor 8 - 225hp MFWD	1,500	1,500	8,582	8,582	1,287	1,287	5.68
Potato Planter 6-Row*	1,740	1,740					0.87
Planter 2 6-Row*	1,740	1,740					0.87
Planter 3 6-Row*	1,740	1,740					0.87
Planter 4 6-Row*	1,740	1,740					0.87
Potato hiller 6-Row*	533	533					0.27
Hiller 2 6-Row*	533	533					0.27
Hiller 3 6-Row*	533	533					0.27
Potato harvester 4-Row*	17,000	17,000					8.50

Table A11. Whole farm equipment operating costs for irrigated russet potatoes in dollars (continued).

	Repairs		Fuel		Lube		Potato operating cost per acre
Equipment	Farm total	Potato portion	Farm total	Potato portion	Farm total	Potato portion	
Harvester 2 4-Row*	17,000	17,000					8.50
Harvester 3 4-Row*	17,000	17,000					8.50
Harvester 4 4-Row*	17,000	17,000					8.50
Harvester 5 4-Row*	17,000	17,000					8.50
Harvester 6 4-Row*	17,000	17,000					8.50
Truck 1 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 2 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 3 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 4 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 5 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 6 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 7 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 8 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 9 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 10 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 11 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 12 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 13 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 14 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 15 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 16 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 17 - Tandem axle	945	945	1,622	1,622	243	243	1.41
Truck 18 - Tandem axle	945	945	1,622	1,622	243	243	1.41

Table A11. Whole farm equipment operating costs for irrigated russet potatoes in dollars (continued).

	Repairs		Fuel		Lube		Potato operating cost per acre
Equipment	Farm total	Potato portion	Farm total	Potato portion	Farm total	Potato portion	
Chisel plow - 37ft*	3,022	755					0.38
Chisel plow 2 - 37ft*	3,022	755					0.38
Tandem Disk - 30ft fold*	3,132	783					0.39
Tandem Disk 2 - 30ft fold*	3,132	783					0.39
Dump Truck 1	270	270	624	624	94	94	0.49
Dump Truck 2	270	270	624	624	94	94	0.49
Fuel Truck 1	540	270	780	390	117	59	0.36
Fuel Truck 2	540	270	780	390	117	59	0.36
Service Truck	540	270	288	144	43	22	0.22
Totals	169,860	146,304	144,275	91,224	21,641	13,684	125.61

*No fuel or lube costs are allocated to these implements because it is accounted for with the tractor to which it is attached.

Table A12. Equipment usage and labor for irrigated russet potato production.

Equipment	Total ann. hrs.	Potato hrs.	Labor hrs/ac potato
Tractor 1 - 350hp track	524	105	
Tractor 2 - 350hp track	524	105	
Tractor 3 - 260hp	401	320	
Tractor 4 - 260hp	455	182	
Tractor 5 - 260hp	455	182	
Tractor 6 - 225hp	433	433	
Tractor 7 - 225hp	433	433	
Tractor 8 - 225hp	433	433	
Potato Planter 6-Row	139	139	0.08
Planter 2 6-Row	139	139	0.08
Planter 3 6-Row	139	139	0.08
Planter 4 6-Row	139	139	0.08
Potato hiller 6-Row	113	113	0.06
Hiller 2 6-Row	113	113	0.06
Hiller 3 6-Row	113	113	0.06
Potato harvester 4-Row	182	182	0.10
Harvester 2 4-Row	182	182	0.10
Harvester 3 4-Row	182	182	0.10
Harvester 4 4-Row	182	182	0.10
Harvester 5 4-Row	182	182	0.10
Harvester 6 4-Row	182	182	0.10
Truck 1 - Tandem axle	196	196	0.11
Truck 2 - Tandem axle	196	196	0.11
Truck 3 - Tandem axle	196	196	0.11

Equipment (continued)	Total ann. hrs.	Potato hrs.	Labor hrs/ac potato
Truck 4 - Tandem axle	196	196	0.11
Truck 5 - Tandem axle	196	196	0.11
Truck 6 - Tandem axle	196	196	0.11
Truck 7 - Tandem axle	196	196	0.11
Truck 8 - Tandem axle	196	196	0.11
Truck 9 - Tandem axle	196	196	0.11
Truck 10 - Tandem axle	196	196	0.11
Truck 11 - Tandem axle	196	196	0.11
Truck 12 - Tandem axle	196	196	0.11
Truck 13 - Tandem axle	196	196	0.11
Truck 14 - Tandem axle	196	196	0.11
Truck 15 - Tandem axle	196	196	0.11
Truck 16 - Tandem axle	196	196	0.11
Truck 17 - Tandem axle	196	196	0.11
Truck 18 - Tandem axle	196	196	0.11
Chisel plow - 37ft	190	48	0.03
Chisel plow 2 - 37ft	190	48	0.03
Tandem Disk - 30ft fold	229	57	0.03
Tandem Disk 2 - 30ft	229	57	0.03
Dump Truck 1	35	35	0.02
Dump Truck 2	35	35	0.02
Fuel Truck 1	100	50	0.03
Fuel Truck 2	100	50	0.03
Service Truck	150	75	0.04
Total equipment labor hours			3.43

*Labor hours are calculated as 1.15 times machine hours. Labor is allocated to implements not to tractors.

Table A13. Price required to break even on fumigation based on expected total yield increases and marketable yield rate improvements.

Yield increase	Increase in Marketable Yield Rate															
	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%	15%
cwt/acre	---*$/cwt*---															
0			51.43	34.29	25.71	20.57	17.14	14.69	12.86	11.43	10.29	9.35	8.57	7.91	7.35	6.86
5	94.74	48.98	33.03	24.91	20.00	16.71	14.34	12.57	11.18	10.07	9.16	8.40	7.76	7.21	6.73	6.26
10	47.37	32.14	24.32	19.57	16.36	14.06	12.33	10.98	9.89	9.00	8.26	7.63	7.09	6.62	6.21	5.76
15	31.58	23.92	19.25	16.11	13.85	12.14	10.81	9.74	8.87	8.14	7.52	6.98	6.52	6.12	5.76	5.33
20	23.68	19.05	15.93	13.69	12.00	10.68	9.63	8.76	8.04	7.42	6.90	6.44	6.04	5.69	5.37	4.97
25	18.95	15.82	13.58	11.90	10.59	9.54	8.67	7.96	7.35	6.82	6.37	5.98	5.63	5.31	5.03	4.65
30	15.79	13.53	11.84	10.53	9.47	8.61	7.89	7.29	6.77	6.32	5.92	5.57	5.26	4.99	4.74	4.36
35	13.53	11.82	10.50	9.44	8.57	7.85	7.24	6.72	6.27	5.88	5.53	5.22	4.95	4.70	4.47	4.11
40	11.84	10.50	9.42	8.55	7.83	7.21	6.69	6.24	5.84	5.50	5.19	4.91	4.66	4.44	4.24	3.89
45	10.53	9.44	8.55	7.82	7.20	6.67	6.22	5.82	5.47	5.16	4.88	4.64	4.41	4.21	4.02	3.69
50	9.47	8.57	7.83	7.20	6.67	6.21	5.81	5.45	5.14	4.86	4.62	4.39	4.19	4.00	3.83	3.51
55	8.61	7.85	7.21	6.67	6.21	5.80	5.45	5.13	4.85	4.60	4.37	4.17	3.98	3.81	3.65	3.35
60	7.89	7.24	6.69	6.22	5.81	5.45	5.13	4.85	4.59	4.36	4.16	3.97	3.80	3.64	3.50	3.20
65	7.29	6.72	6.24	5.82	5.45	5.13	4.85	4.59	4.36	4.15	3.96	3.79	3.63	3.48	3.35	3.06
70	6.77	6.27	5.84	5.47	5.14	4.85	4.59	4.36	4.15	3.96	3.78	3.62	3.47	3.34	3.21	2.94
75	6.32	5.88	5.50	5.16	4.86	4.60	4.36	4.15	3.96	3.78	3.62	3.47	3.33	3.21	3.09	2.82
80	5.92	5.53	5.19	4.88	4.62	4.37	4.16	3.96	3.78	3.62	3.47	3.33	3.20	3.08	2.98	2.72
85	5.57	5.22	4.91	4.64	4.39	4.17	3.97	3.79	3.62	3.47	3.33	3.20	3.08	2.97	2.87	2.62
90	5.26	4.95	4.66	4.41	4.19	3.98	3.80	3.63	3.47	3.33	3.20	3.08	2.97	2.87	2.77	2.53
95	4.99	4.70	4.44	4.21	4.00	3.81	3.64	3.48	3.34	3.21	3.08	2.97	2.87	2.77	2.68	2.44
100	4.74	4.47	4.24	4.02	3.83	3.65	3.50	3.35	3.21	3.09	2.98	2.87	2.77	2.68	2.59	2.36

Table note: based on a yield of 350 cwt per acre without fumigation, and a marketable yield rate of 76% without fumigation.