A Cost Analysis on the use of *Solanum sisymbriifolium* as a Trap Crop for *Globodera pallida*

A Thesis

Presented in Partial Fulfillment of the Requirement for the

Degree of Master of Science

With a

Major in Agricultural Economics

in the

College of Graduate Studies

University of Idaho

by

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August 2018

Authorization to Submit Thesis

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Abstract

The pale cyst nematode (PCN), *Globodera pallida*, has been causing economic and pest control problems in Idaho since it was discovered in 2006. The discovery and subsequent quarantine and regulation initially caused our trading partners Korea, Mexico, and Canada to cut off all importation of Idaho potatoes, while Japan cut off importation of all U.S. potatoes. Currently, there are 27 infested, quarantined fields comprising 3,043 acres. Including the quarantined fields, a total of 8,220 acres in the southeast Idaho counties of Bingham and Bonneville are regulated. Potatoes are not allowed to be grown in the quarantined fields. Although the current eradication program is keeping PCN contained to those two counties, methyl bromide (MeBr), the main fumigation product, is no longer being allowed, and the alternative fumigant, 1,3-dichloropropene (DCP), is not effectively eradicating PCN from the soil. Thus, growers are not allowed to plant their most profitable crop, potatoes. However, using litchi tomato, *Solanum sisymbriifolium* Lam., as a trap crop to eradicate PCN may be viable. Under simulations which I have conducted I have found that adding *Solanum sisymbriifolium* to the current eradication program so that potatoes can eventually be planted is more cost-effective than not using *Solanum sisymbriifolium* and only growing wheat and barley.

Acknowledgements

I would like to extend a special thank you to all of those that made this experience possible. First of all, I would like to thank my major professor Dr. McIntosh for his patience, advice, broadening my agriculture education, and help every step of the way. I would also like to thank my committee members Dr. Hutchinson and Dr. Winfree for their insight and persistence. I want to also say thank you to Norm Ruhoff for taking a special interest in me and always being at hand when I needed him. To all of the faculty and staff in this department, thank for making this experience enjoyable all the way to the end. Thank you to Dr. Tozer and Dr. Brady from WSU for taking time out of their days to meet with me and help me find a graduate program that would best fit my career aspirations. I also want to extend a thank you to the employees of Syngenta, specifically Mike Sandmann, Josh Adkins, and Micah Scanga for being my mentors the past three summers and pushing me to my fullest potential. Lastly, I would like to thank the Jake Hume Scholarship Committee and Washington State Potato Foundation for awarding me a scholarship every year I attended college. Without your support this would not have been possible.

Dedication

This work is dedicated to my parents, Mike and Julie Dodds, for their constant support and belief in me. Without you none of this would've been possible, I am forever in your debt. To the rest of my family, Toni, Claudette, Deanna, Joe, Gary, Earl, and Linda thank you for always looking out for me.

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Chapter 1 Introduction

Currently, the number one priority for the Idaho potato industry is to eradicate pale cyst nematode (PCN), *Globodera pallida,* from fields in southeast Idaho (Dandurand et al., 2014). PCN is an internationally recognized quarantined pest and is widely found throughout the world, but in North America before 2006, it was only present in Newfoundland, Canada (USDA APHIS, 2017a). In 2006, however, PCN was found in Idaho in the soil of a potato processor's cull pile – culls are potatoes that are not suitable for fresh pack or processing (MSU, 2010). Soon after that discovery, the Animal and Plant Health Inspection Service (APHIS) and Idaho State Department of Agriculture (ISDA) conducted surveys to determine the possible origin and distribution of PCN in Idaho and confirmed seven infested fields all within a one-mile radius in the southeast Idaho counties, Bingham and Bonneville. A 10,000-acre regulatory area encompassing the infested and associated fields was established. To date, APHIS and ISDA have found 27 PCN-infested fields totaling 3,043 acres. Those fields have been quarantined and potatoes cannot be grown. Fields with known associations to infested fields, such as past use of the same equipment, are categorized as regulated. Including the infested fields, a total of 8,220 acres are currently regulated in Idaho (USDA APHIS 2018). These fields are located in Bingham and Bonneville counties. Through an intensive soil sampling and nematode analyses program, PCN has not been found outside this area and nowhere in the rest of the United States (USDA APHIS 2017b).

APHIS and ISDA currently have an eradication program for PCN, which until 2014, relied on fumigation with methyl bromide (MeBr). Due to regulatory and other concerns, MeBr is no longer being used and the alternative fumigant, 1,3-dichloropropene (DCP) is not working as timely as desired.

Figure 1.1 Fields Under Regulation in Bingham and Bonneville County

Along with the 2006 detection of PCN in Bonneville and Bingham counties came economic concern with Canada, Korea, and Mexico shutting down all importation of Idaho potatoes, and even more extensively, with Japan shutting down importation of all United States potatoes (USDA APHIS, 2017a). Since 2006, APHIS and ISDA have conducted a massive number of soil surveys in all of Idaho's potato producing areas as well as other United States production areas, however, no PCN has been detected. Thus, indicating that PCN has been contained to Bonneville and Bingham county (USDA APHIS, 2017a) and insuring our trading partners that it is safe to import Idaho potatoes from outside the regulatory area without concern of introducing PCN to their agriculture producing land. As a result, Canada, Mexico, and Korea have re-opened importation of all Idaho potatoes except for potatoes grown in Bonneville and Bingham county (Dandurand et al., 2014). Japan has also re-opened its markets to United States potatoes, and in September 2017, began to accept potatoes from Idaho except for Bingham and Bonneville counties (USDA ARS 2018).

Background

PCN are soil-borne organisms that actually do not attack potato tubers, but instead attack and infest the roots of the potato plant (USDA, 2010). PCN can cause devastating damage to a potato crop, and if left uncontrolled can cause up to 80% crop loss. For example, with Idaho's average yield of 425 cwt/acre in 2017, PCN could cause 42,500 cwt yield loss on an average 125-acre field (NASS, 2017). Symptoms caused by PCN infecting the potato roots are poor root development, plant wilting, stunted growth, early plant death, and drastic reduction of potato tuber size. Once the PCN females have completed their life cycle they attach themselves to the roots of their host plant and die forming a cyst. Each cyst can contain 200 to 600 eggs and those eggs can stay viable in the soil for up to 30 years. (Dandurand et al., 2014) have determined that for every 20 PCN eggs per gram of soil there can be a 20 cwt per acre loss. When a host crop, such as potato, is planted, the roots release an exudate into the soil which, in turn, causes the eggs to hatch from the cyst (Timmermans et al., 2007). The exudate contains chemical compounds which stimulates the eggs and indicates a host plant is present.

PCN spreads primarily by transport of the cysts in soil (USDA, 2010). This mainly occurs by farming implements, construction equipment, and other equipment moving from one infested field to others, and while doing so, transferring soil that contains PCN cysts to fields that do not already contain PCN.

After PCN was first detected in Idaho, APHIS and ISDA released an environmental assessment (EA) in May of 2007, on how to take on the PCN problem (USDA, 2017). The suggested treatment was the use of MeBr or DCP alone or in combination. Sold as Telone II,DCP is labeled for a maximum of one application per growing season at a rate of 177 pounds of active ingredient (ai) per acre. The first treatment of MeBr occurred May of 2007, and there was a realization for a need to have the option to apply DCP twice a year to increase effectiveness (USDA, 2017). Therefore, Idaho was allowed a site specific, special local needs label (SLN, Section 24(c)) under the Federal Insecticide Fungicide and Rodenticide Act (FIFRA) for the option of two DCP applications per season and a rate range of 177 to 354 pounds ai per acre (USDA, 2017).

Since 2014, however, MeBr is no longer being used in the eradication program (USDA, 2017). Concerns had been raised by the public regarding its use in treating PCN-infested fields. Growers also had concerns that MeBr might completely sterilize and perhaps even permanently damage the soil after repeated treatments. Furthermore, In 2013 and 2014, farms in southeastern Idaho had cattle that experienced oozing lesions, excess fluid, spontaneous calf aborting, and stillbirths after being fed forage grown in fields which had been treated with MeBr (AP, 2016). Calves that were born alive struggled to stand, nurse, and breathe. Subsequent laboratory tests confirmed excessively high levels of inorganic bromide in the forage crops and the cows. Approximately $450,000 of loss for each farm occurred. Thus, DCP is the only chemical fumigant being used and effective alternatives to chemical fumigation are urgently needed.

***Solanum sisymbriifolium* as a Trap Crop**

Solanum sisymbriifolium also known as Litchi tomato, Sticky nightshade, and Fire and Ice Plant, is an annual herb native to South America, but is currently distributed throughout the world and can grow as tall as 90 cm high (Scholte, 2000). The stems and branches are covered in prickles which can be as long as a ½ inch, and the flowers are white to pale blue. *Solanum sisymbriifolium* and potato, *Solanum tubersom*, are both in the *Solanaceae* family and share similar biological characteristics, such as flowering and genetic structure.

Trap crops are used throughout agriculture to control pest populations. By planting trap crops growers are able to bait pests into thinking a viable host is present, but the crop planted actually kills the pest. Just like potatoes, *S. sisymbriifolium* roots exude a chemical compound into the soil which causes the PCN eggs to hatch, but unlike potatoes, *S. sisymbriifolium* is resistant to PCN. After egg-hatch, the nematodes are unable to feed on the roots of *S. sisymbriifolium* and die before reaching maturity and ability to produce eggs (Dias et al., 2012). In other words, the PCN population is depleted. One advantage of a trap crop like *S. sisymbriifolium* is that its roots are able to go deeper in the soil than a fumigant without the same environmental repercussion (Dandurand et al., 2014). *S. sisymbriifolium* has also proven itself to grow well in southern Idaho’s climate during field trials and can be planted using a grain drill. Which is Important because growers won't have to buy special machinery to plant *Solanum sisymbriifolium* due to wheat being a primary crop in the area.

Potential Risk

Although *S. sisymbriifolium* originated in South America, it is found in 17 states as well as in eastern Canada, but is not listed as a noxious weed in any of these places (USDA 2018). Any introduced species, however, has the potential to become a pest without proper management. Since it is not native to Idaho, the ISDA has placed *S. sisymbriifolium* in a special invasive species category for trap and biofumigants crops and a strict permitting process must be followed in order to grow it in Idaho (USDA, APHIS 2017). The University of Idaho is conducting field trials to determine which herbicides can be used so that *S. sisymbriifolium* does not become a weed. Herbicides such as Roundup PowerMax (glyphosate) and Starane Ultra (fluroxypyr 1-methylheptyl ester), have been shown to kill S. sisymbriifolium, and more herbicides are being tested for killing S. sisymbriifolium at the end of the growing season, as well as controlling it in crops planted in subsequent years (Dandurand et al., 2014). Herbicides safe to *S. sisymbriifolium* must also be found so that weeds, especially those which can host PCN, such as hairy nightshade (*Solanum physalifolium*) can be controlled while growing the trap crop. Until a complete herbicide management plan is developed and accepted, the permitting remains in place and includes five years of fencing and monitoring fields in which the trap crop has been grown (Daundurdand et al., 2014). In addition to the herbicide trials, researchers from the University of Idaho are conducting lab, greenhouse, and field trials testing the effectiveness of *S. sisymbriifolium* for controlling PCN. Work is also being done to breed *S. sisymbriifolium* for more desirable characteristics such as reduced prickles, rapid germination, reduced flowering, reduced berry set, greater root mass, and higher production of the exudate hatching factor.

S. sisymbriifolium is currently not a tradable commodity. Since it has to be grown long enough in the season to cause PCN eggs to hatch but nematode death before reproduction, there is not enough time to grow a second, profitable crop the same season.

Therefore, if growers wish to add *S. sisymbriifolium* to part of their PCN eradication program, they would have to sacrifice the revenue from that growing season. *S. sisymbriifolium* has shown promising results with possible eradication of PCN in one season, however, some growers might not be able to take the financial blow of not having revenue from a field for a year. In contrast, if they are able to give up a growing season to S. sisymbriifolium, there is a possibility growers may be able to plant potatoes the next year if PCN is eradicated in the field. This is important because potatoes generated $18,520/acre in profit on average compared to hard red spring wheat's average profit of -$6,035 and malted barley's average profit of $4,086.25 in eastern Idaho for 2015 (UI, 2015).

Along with the risk of *S. sisymbriifolium* becoming a weed in south eastern Idaho, it has the potential of hosting detrimental potato pests such as potato psyllids (*Bactericera cockerelli*), an insect vector for zebra chip disease (NSW, 2012) and late blight (*Phytophthora infestans*) (Flier et al. 2003). Zebra chip attacks the potato by disrupting dormancy which causes premature sprouting, internal sprouting, and tuber chaining, making seed potatoes unacceptable to plant. For potatoes grown for processing, the disease will cause a stripped discoloration on fried cross sections, causing the potato crisps to have a burnt taste and appearance, making the potatoes unmarketable. Currently, zebra chip is found in the United States, Canada, Mexico, Guatemala, Honduras, and New Zealand with the potential to cause 60-100% of yield loss (NSW, 2012). With Idaho's average yield of 425 cwt/acre in 2017, zebra chip can cause 31,875-53,125 cwt of yield loss on an average 125-acre field (NASS, 2017). Zebra chip is not yet predominately found in the northwest, but is in Texas where it causes 35.5 million in loss annually.

There are control methods for psyllids. First, a sampling program is needed in order to monitor psyllid populations and to conduct decision-making strategies (Rondon et al., 2012). Yellow sticky cards can be used to detect early psyllid populations and psyllid migration into and out of fields. The sticky cards should be placed out at the beginning of the potato growing season and replaced once a week. There is no recommended amount of traps to set, but more traps increase the chance of early detection (Robinson et al., 2016). The use of a sweep net and DVAC (inverted leaf blower) is recommended to capture adult psyllids, due to their ability to fly or jump when disturbed. Lastly, 10 leaf samples should be collected from 10 different locations on the 10 outer rows of the field to scout for eggs and nymphs (Schreiber et al., 2012). When sampling, make sure to consider features in the landscape that are more suitable for adults settling from the air (Bradshaw et al., 2011). For example, tree lines can create eddies that could have a greater population of psyllids in fields downwind. The sample leaves need to be full sized leaves and located in the middle of the plant. Nymphs will be located on the underside of the leaf, but can be found on shaded upper leaf surfaces (Cranshaw, 2013). Eggs are most commonly found on the underside and the leaf's edge in the upper canopy. However, this sampling method is not meant for early detection, if psyllids are found on the leaves this only confirms that the population has established itself and zebra chip infection has already begun (Rondon et al., 2012).

The second step in controlling potato psyllids is a pesticide rotation. There are many insecticides registered on potatoes that can control psyllids in their adult and immuture stages (Rondon et al., 2012). Some insecticides that are able to control the nymph and adult life stages are also able to control eggs. In locations where zebra chip has been problematic, season long, weekly applications are recommended. Although, in the PNW this might not be the case due to psyllids not being expected to be in the field during the early part of the growing season. Currently, the most effective pesticide before planting is imidacloprid and during the growing season the use of abamectin, spiromesifen, and spinosad is recommended (Godfrey and Haviland, 2008). Rotating active ingredients is crucial to proper integrated pest management strategies this way the insect isn't able to develop resistance (Robinson et al., 2016).

Research Overview

The remainder of this paper will discuss in detail the three research objectives. Chapter 2 considers alternative control methods for PCN and efficacy of *S. sisymbriifolium* as a trap crop. Chapter 3 contains the construction of a cost of production for *S. sisymbriifolium* and crop rotations in Bingham and Bonneville county. Chapter 4 covers the estimated distribution of costs associated with crop rotations containing *S. sisymbriifolium*. Lastly, Chapter 5 gives final conclusions and discussion

Chapter 2 Lit Review

Introduction

Pale cyst nematode (*Globodera pallida*) (PCN) is a relatively new problem to Idaho, but *Gobodera* sp. have been causing crop damage around the world for decades, approximately $34,395,480 in economic loss per year in the United Kingdom (UK) alone (Green et al., 2012). If left unrestricted in Australia, it is estimated that *Globodera* sp. could cause up to $370 million in economic loss over the next 20 years (Hodda and Cook, 2009). With such dramatic and potential economic damage, the world is searching for ways to control PCN and other *Globodera* sp. While *Globodera* sp. is too abundant in many countries to be eradicated and can only be managed, other countries (especially European) have developed methods which may be useful for PCN eradication in Idaho.

Objectives

The objectives for this chapter were to:

1. Understand current methods utilized for controlling PCN outside of the United States
2. Analyze results and data from previously conducted *Solanum sisymbriifolium* field trials

PCN Alternative Control Methods

In Europe, *Globodera* sp. is managed with a combination of partial resistance, the use of nematicides, and a long crop rotation (Dandurand et al., 2014). In a Scotland study, researchers found that during the first six years without a host plant in infected soil, there was a drastic reduction in viable *Globodera* sp. eggs, thus a minimum six-year rotation has been recommended. In the UK, researchers have also found that a long rotation is needed to manage PCN populations (Trudgill et al., 2003). With a combination of partially resistant potato cultivars and a 9-year rotation in a sand soil, populations were kept below 5 eggs g^{-1}, which is sufficient for potato production. When only using a five-year rotation, the population increased to 20 eggs g^{-1} and resulted in a 75% yield decrease. However, a 3-year rotation was sustainable only if every partially resistant potato crop is treated with 80% effective granular nematicide (Trudgill et al., 2003).

More than 40% of the 150,000 ha of potatoes grown in the UK are infested with *Globodera* sp., 75% of these infestations are predominately PCN (Halford et al., 1999). The other 25% is infested with *Globodera rostochiensis*, (golden nematode (GN)). GN is only found in the U.S. in the state of New York (USDA, 2015). One method used to control *Globodera* sp. is planting resistant potato cultivars that cause the nematodes to hatch but do not allow them to reproduce (Halford et al., 1999). However, a cultivar that is resistant to GN is not necessarily resistant to PCN. Moreover, there are currently no cultivars fully resistant to PCN. Halford et al. (1999) conducted a study in which they planted the resistant cultivars Arran Comet, Maris Bard, Maris Peer, Maris Piper, Rocket, Santé, and Cara in infested soil April, June, and August and grew them for 5, 6, and 7 weeks before removal of the plants by hand. The results showed that planting Sante' in June provided the best reductions in overall *Globodera* sp. population density with a reduction of up to 95% (Halford et al., 1999). When only counting PCN populations, both Cara and Santé were effective. Planted in August and grown for 7 weeks, Cara reduced the population by 63% and Santé by 64%.

A survey conducted in England and Wales found that out of 484 potato growers in the region, 64% of them had fields infested with *Globodera* sp. (Minnis et al., 2002). In those fields, 67% were infested with PCN, 8% with GN, and 25% with a combination of both. *Globodera* sp. control in this area requires a combination of crop rotation, resistant cultivars, and trap cropping. In 1996, 45% of all potatoes planted in the survey area had resistance to GN and 7% had partial resistance to PCN along with full resistance to GN. Comparing sample results from 1996 and 2002, PCN populations have increased at a faster rate (13%) than populations of GN (3%) (Minnis et al., 2002). This difference could be due to lack of growing cultivars that contain even partial resistance to PCN. Also in the region, there has been a reduction in the number of growers, leading to a smaller concentrated area of production and shorter rotations which, in turn, encourages PCN population growth. In fact, 50% of the sampled farms had only 1 to 5 year-long rotations (Minnis et al., 2002).

Although the use of resistant cultivars and long rotations may work for European agriculture, they are not feasible for the Idaho potato grower (Dandurand et al., 2014). Currently, there is not a PCN-resistance gene in Idaho's signature russet varieties and a seven-year crop rotation will only suppress, not eradicate Idaho PCN populations. In addition, Idaho fields infested with PCN are quarantined and regardless of cultivar, potatoes are not allowed to be grown in them. However, there is one control method that the Europeans use which could be applicable to Idaho agriculture - the use of *S. sisymbriifolium* as a trap crop.

Previous *Solanum sisymbriifolium* Trials

Studies at the University of Idaho testing the efficiency of *S. sisymbriifolium* controlling PCN in a greenhouse environment have shown positive results. When planting potatoes after *S. sisymbriifolium* had been grown in PCN-infested soil, only 1 PCN cyst was found compared with finding 271 cysts when nothing had been planted in the infested soil before planting potatoes and 1,021 cysts when planting potatoes back to back (Dandurand et al. 2014). *S. sisymbriifolium* has grown well in southern Idaho's climate during field trials and can be planted using a grain drill. Therefore, growers will not have to buy special machinery since wheat is a primary crop in the area.

In Europe, growers have been using *S. sisymbriifolium* for years and seed is sold commercially (Dias et al., 2012). One source of *S. sisymbriifolium* seed is priced at $402.98/ha (Sparks, 2013). In studies conducted in the Netherlands in heavily- infested soils, up to 85.3% of a *Globodera* sp. population was diminished by the use of *S. sisymbriifolium* as a trap crop (Sparks, 2013).

Another study conducted in the Netherlands also found that *S. sisymbriifolium* has great potential as a trap crop for PCN (Scholte and Vos, 2000). Not only did *S. sisymbriifolium* have strong hatch stimulation for *Globodera* sp., but it was completely resistance to both GN and PCN. The trials tested how much potato, *S. sisymbriifolium*, white mustard, and black nightshade (*S. nigrum*) caused *Globodera* sp. eggs to hatch. Potato and *S. sisymbriifolium* caused egg hatching of 87 and 77%, respectively, in soils moderately infested with two-year old cysts at a population of 2-29 juveniles' ml^{-1} air dried soil (Scholte, 2000; Scholte and Vos, 2000). Potato and *S. sisymbriifolium* caused egg hatching in soils moderately- to heavily-infested with one-year old cysts 74 and 60%, respectively. In soil very heavily infested with a *Globodera* sp., potato, and *S. sisymbriifolium* had their least amount of egg hatch at 69 and 52%, respectively. Roots of potato and white mustard were mostly found in the top 10 cm of soil, whereas roots of black nightshade and *S. sisymbriifolium* were found at depths of 20-30 cm and 10-20 cm, respectively, which might give the latter two species a better chance of stimulating PCN hatch.

While no large-scale *S. sisymbriifolium* efficacy field trials have been conducted in the U.S., there have been greenhouse trial (Dandurand and Knudsen 2016). Studies were conducted simulating three different cropping systems: potato, *S. sisymbriifolium*, and soil only (fallow), each followed by potato. Also, each cropping system was either planted with or without a combination of two biological control agents, *Trichoderma Harzianum* and *Plectospharella cucumerina*. The researchers placed soil in clay pots, infested it with PCN at a rate of 5 eggs g^{-1} of soil, then planted potato or *S. sisymbriifolium*, or left the soil fallow (Dandurand and Knudsen 2016). Sixteen weeks later, the plants were removed and the soil was refrigerated at 4 degrees C for 8 weeks, and then planted to potatoes. Once the potatoes grew for 16 weeks, cysts were counted. The PCN population was dramatically reduced by 99% in potato following *S. sisymbriifolium*. Soil treated with *P.* cucumerina and left fallow, decreased the population by 88% in the following potato crop and 88% was also found in the treated soil with potato following potato, but this statistic was not consistent across all experiments (Dandurand and Knudsen 2016). Soil amended with *T.harzianum* decreased PCN population by 42-47% in potato following potato, but not in the other crop systems.

In 2015, a trial was conducted in a southeast Idaho field in contained 5-gallon bucket microplots seeded with lab-reared cysts contained in nylon-mesh bags to achieve a rate of 5 eggs/g soil. The field had not been fumigated with MeBr or DCP. Buckets were either planted with *S. sisymbriifolium* or left bare. As in the greenhouse trial, soil in the microplots was or was not amended with a combination of the biological control agents, *T. harzianum* and *P.*

cucumerina. At eight weeks, PCN egg content of cysts were 42% less in microplot soil where *S. sisymbriifolium* was being grown compared to reduction in the bare soil control. After 10 weeks, *T. harzianum* and *P. cucumerina* applied alone reduced egg content by approximately 25-30%, but when applied in combinations with *S. sisymbriifolium*, egg content was reduced by 70 to 83% compared to the bare soil only control.

S. sisymbriifolium was planted in PCN-infested grower fields in southeast Idaho in 2015, 2016, and 2017. The 2015 planting occurred in three infested fields (132 acres). Testing at the end of the 2015 growing season did not detect any viable PCN cysts in two of the three treated fields, and no PCN cysts were found on the third field following testing in 2016 (USDA APHIS 2017b).

S. sisymbriifolium has been allowed to grow up to 21 weeks in the Netherlands, whereas, in southern Idaho, under current permitting, the trap crop must be destroyed before mature berries and seed are produced. So, it is only allowed to grow for 8 to 9 weeks after emergence (Dandurand et al., 2014). Interestingly, in shorter length, Idaho field trials, *S. sisymbriifolium* roots reached depths up to 5 feet and in the longer Netherland experiments, the roots were only reaching 3 feet.

My objective for this paper is to find out if using *S. sisymbriifolium* as trap in Idaho's PCN eradication program is more cost-effective than not using *S. sisymbriifolium* and having to continue the current program.

Chapter 3 Comprising Crop Rotations and *Solanum sisymbriifolium* Cost of Production

Introduction

Crop rotations have been an essential part of agriculture for many years. By establishing an effective crop rotation, growers are able to manage pests, enhance soil fertility, enhance soil structure, produce larger yields, and lower input costs (Hopkins et al., 2004).

Pests (i.e. weeds, pathogens, and insects) populations are all able to develop resistance to pesticides (Oerke, 2006). A naturally occurring, 1 in a million, biotype resistant to a given pesticide(s) mechanism of action can be present in a population. When applying that pesticide, the naturally resistant pest is able to survive and reproduce. The continuous use of pesticides with the same mechanism of action allows the initially small amount of survivors to multiply and eventually dominate a pest population. Rotation of crops allows a grower to use multiple pesticides with multiple mechanisms of action, which can prevent or delay the development of resistance (Oerke, 2006).

Planting crops such as potatoes, without multiple years apart can reduce soil fertility and structure. Essential soil properties affect nutrient cycling, erosion potential, compaction, organic matter, and biological diversity and activity. Potatoes can absorb high rates of nutrients and when harvested, these nutrients are removed from the soil with the potatoes, leaving the next crop with less readily available soil nutrients possibly causing growers to use more fertilizer which, in return, drives input costs up (Parent et al., 1994). Such nutrients include nitrogen, potassium, phosphorus, calcium, magnesium, sulfur, and chloride (Hopkins et al., 2004).

Potatoes can also increase the risk of soil erosion (Peters et al., 2003). The production of potatoes includes multiple tillage practices, compared to other crops that require minimum tillage. Soil erosion increases the risk of losing valuable topsoil that holds important chemical, physical and biological properties which are not as abundant in subsoil

(Peters et al., 2003). Thus, rotation of potatoes with crops that require minimum field activities is recommended.

A study by the University of Idaho proved that a 40 cwt/acre loss along with reduction in tuber size and quality is achieved for each year less than four between potato crops (Hopkins et al., 2004). A three-year rotation is common in Bingham and Bonneville counties and a few growers use what they call a “snow” rotation, which is growing potatoes back-to-back years.

Cost of productions can be utilized to determine the amount of input and output energy used in agriculture production and is helpful in achieving an economic analysis in a production region. Zangeneh et al. (2010) configured a cost of production for potatoes in the Hamadan province of Iran to better understand the amount inputs used and benefits to potato growers, similar to the objective for our study.

Cost of production analyses include many input variables, such as, fertilizer, pesticides, ownership costs, custom consulting, and water. All input prices are the average over a large region. They also include the average yield and price to derive potential revenue and profit. Having this information at hand allows growers to make profit maximizing decisions and plant crops that will deliver the largest profit.

The University of Idaho constructs cost and return estimates also known as enterprise budgets for each crop grown in Idaho. The enterprise budgets are further broken down into regions, counties, irrigated crops, and dryland crops, allowing growers to be confident in the data for their region.

Objectives

The objectives of this study were to:

1. Develop realistic crop rotation containing *S. sisymbriifolium*
2. Construct a cost of production for *S. sisymbriifolium*

Materials and Methods

In order to meet our objectives, multiple stages of research were mandatory. First, was to contact industry experts from Bingham and Bonneville county to find the most common potato rotation in the area. Their opinions were conglomerated to construct three different possible crop rotations. The next was to contact University of Idaho faculty conducting *S. sisymbriifolium* field trials in southeastern Idaho. Lastly, contact three anonymous pesticide retailers. Together their responses derived a cost of production for *S. sisymbriifolium*.

Crop Rotation Interviews

For the simulations in our study to be respected, correct crop rotations were needed. Four different industry expects from southeastern Idaho were contacted to establish the most predominate potato rotation in Bingham and Bonneville county. The experts were picked based on years in the potato industry and amount of contact with potato growers from the given region.

Interviews were conducted over the phone during the month of April 2018. The sole question of the interviews was what crop rotation is most used in Bingham and Bonneville county while growing potatoes. Given the interviewees years in the industry, four was a sufficient amount.

***Solanum sisymbriifolium* Interviews**

In order to derive a cost of production for *S. sisymbriifolium* I interviewed University of Idaho Potato Cropping Systems Weed Scientist, Dr. Pamela J.S. Hutchinson who is currently conducting *S. sisymbriifolium* herbicide management field trials in southeastern Idaho. The interview was administered in October, 2017. The main focus of the interview was to determine inputs (i.e. pesticides including herbicides, amount of water, machinery type, and fertilizer) contributing to the production of *S. sisymbriifolium*. This interview played the largest role in producing the cost of production for *S. sisymbriifolium*.

Results

With the response from the industry experts it enabled the development of crop rotations for Bonneville and Bingham county. Along with Pam Hutchinson's response I was able to derive a cost of production for *S. sisymbriifolium*. Together I was able to construct crop rotations including *S. sisymbriifolium*. The results from the interviews are presented individually in this section

Solanum sisymbriifolium Cost of Production

S. sisymbriifolium has been successfully grown in fields in Bingham and Bonneville counties with the same equipment and amount of irrigation used to grow spring wheat. Therefore, I used the University of Idaho crop budget for spring wheat as a base model to derive cost of production for *S. sisymbriifolium*. As mentioned, herbicide management for *S. sisymbriifolium* includes weed control in the trap crop and killing it at the end of the growing season. Matrix (rimsulfuron) 25 DF at a rate of 1.5 oz/acre plus Sonalan HFP (ethalfluralin) at a rate of 2 pints/acre can be safely used to control weeds in *S. sisymbriifolium*. Roundup PowerMax (glyphosate) at a rate of 22 oz/acre, tank mixed with 0.4 pints/acre Starane Ultra (fluroxypyr 1-methylheptyl ester) will kill *S. sisymbriifolium* at the end of the season. In order to gather the respected herbicides prices, I contacted three different ag chemical retailers. Due to bulk discounts and other factors, pesticide prices can be different for different growers, therefore I asked the retailers for their high and low price of each of the herbicide to develop an average price. Prices will not be listed in order to abide by the wishes of the retailers to stay anonymous and keep the information confidential. After entering the averaged herbicide prices and rates along with the aforementioned Idaho crop budget, the cost of production for *S. sisymbriifolium* was determined to be $515.65/acre.

Crop Rotation analysis

The Industry experts provided multiple crop rotations that are utilized in Bonneville and Bingham county. Crops predominately grown in the area included potatoes, wheat, barley, corn, beets, and oil seed. Nonetheless, some crops occurred more than others in grower's rotations. A summary of their responses can be seen in Table 3.2.

Table 3.2 Summary of Industry Expert Responses

Crop Rotation	**Industry Expert 1**	**Industry Expert 2**	**Industry Expert 3**	**Industry Expert 4**
Potato, Wheat, Barley, Potato	Most Likely	Most Likely	Most Likely	Most Likely
Potato, Grain, Beet, Potato	Somewhat Likely	Somewhat Likely	Somewhat Likely	Somewhat Likely
Potato, Corn, Grain, Potato	Least Likely	Least Likely	Least Likely	Least Likely
Potato, Oil Seed, Grain, Potato	Least Likely	Least Likely	Least Likely	Least Likely

Against the recommendation of having a four-year potato crop rotation, most growers in Bonneville and Bingham county use a three-year rotation. With potatoes in year 1, year 2: wheat, year 3: barley, and then repeating the rotation. Beets were mentioned to commonly be in the rotation, but at an irrelevant amount. Corn and oil seed are also grown in the counties, but also at an inconsiderable amount, forcing me to exclude them from my crop rotation.

By deriving crop rotations I will be able to estimate the mean net present value of each one and compare and contrast to which rotation benefits the grower most on a profit basis.

Crop Rotations

Compiling the results from the industry experts, Pam Hutchinson, and chemical retailers three different crop rotation scenarios are posited including *S. sisymbriifolium*. Each crop rotation will be discussed and presented in this section.

Crop Rotation A will represent that *S. sisymbriifolium* is effective in eradicating PCN in one year and will only include *S. sisymbriifolium* in year one. This due to the studies conducted by (Dandurand et al., 2014) and (Dandurand et al., 2016) with results of *S. sisymbriifolium* potentially eliminating PCN in one growing season. A rotation of potatoes, wheat, and barley will then be used based off the industry expert responses. Crop Rotation A can be seen in Table 3.3.

Table 3.3 Crop Rotation A

Crop Rotation A	
Year	**Crop**
Year 1	*Solanum sisymbriifolium*
Year 2	Potato
Year 3	Wheat
Year 4	Barley
Year 5	Potato
Year 6	Wheat
Year 7	Barley
Year 8	Potato
Year 9	Wheat
Year 10	Barley
Year 11	Potato
Year 12	Wheat
Year 13	Barley
Year 14	Potato
Year 15	Wheat

Crop Rotation B will contain two years of *S. sisymbriifolium*. This rotation considers the possibility that *S. sisymbriifolium* will not fully eradicate PCN in one growing season. Therefore, it is still planted in year one, however, rather than potatoes which hosts PCN to maturity and allows reproduction, wheat will be planted in year 2. The rotation will go in the order of *S. sisymbriifolium* will be planted in year one, year 2: wheat, year 3: *S. sisymbriifolium*, year 4: will then begin the same potato, wheat, and barley rotation as Crop Rotation A. Crop Rotation B can be found in Table 3.4.

Table 3.4 Crop Rotation B

Crop Rotation B	
Year	**Crop**
Year 1	*Solanum sisymbriifolium*
Year 2	Wheat
Year 3	*Solanum sisymbriifolium*
Year 4	Potato
Year 5	Wheat
Year 6	Barley
Year 7	Potato
Year 8	Wheat
Year 9	Barley
Year 10	Potato
Year 11	Wheat
Year 12	Barley
Year 13	Potato
Year 14	Wheat
Year 15	Barley

Crop Rotation C will also contain two years of *S, sisymbriifolium*, but at different years than Crop Rotation B. Year 1 *S. sisymbriifolium* will be planted, year 2: wheat, year 3: barley, year 4: wheat, year 5: *S. sisymbriifolium*, and then the same potato, wheat, and barley rotation will be used as Crop Rotations A and B. In Crop Rotation C, *S. sisymbriifolium* is grown in different years than Crop Rotation B to consider the fact that not all growers can financially support growing *S. sisymbriifolium* with only one year of an alternative crop between growing seasons. Growing *S. sisymbriifolium* will only produce costs for a grower, not profit. Some growers could need more sustainable revenue than others to keep their farm out of uncomfortable debt. Crop Rotation C is provided in Table 3.5.

Table 3.5 Crop Rotation C

Crop Rotation C	
Year	**Crop**
Year 1	*Solanum sisymbriifolium*
Year 2	Wheat
Year 3	Barley
Year 4	Wheat
Year 5	*Solanum sisymbriifolium*
Year 6	Potato
Year 7	Wheat
Year 8	Barley
Year 9	Potato
Year 10	Wheat
Year 11	Barley
Year 12	Potato
Year 13	Wheat
Year 14	Barley
Year 15	Potato

Chapter 4 Determining the Distribution of Costs for a *Solanum sisymbriifolium* Crop Rotation

Introduction

A crop rotation including *S. sisymbriifolium* will inevitably contain a higher initial cost than one without due to *S. sisymbriifolium* not being a tradable commodity, but in the long run can be potentially more profitable. PCN is a threat that could potentially destroy the Idaho potato industry and continue to cause economic damage if not stopped, like it has been doing for decades in Europe. Once established throughout a country PCN is ultimately impossible to eradicate making eradication in Idaho a top priority for the potato industry. It has been proven throughout the literature that there are limited methods of control for PCN and that these controls are limited in efficacy in controlling PCN populations. *S. sisymbriifolium* has established that it is the most effective control for PCN, along with resistant cultivars in past studies. Yet Idaho's varieties do not carry the resistant genes making *S. sisymbriifolium* the optimal control method.

Before a grower adopts *S. sisymbriifolium* into their crop rotation it is important for them to know the costs associated with it. To date, there have been no studies in the U.S. to determine the potential costs associated with growing *S. sisymbriifolium*. This study was conducted with that individual purpose in mind.

Objectives

The objectives for this chapter were to:

1. Determine the cost associated with each input defined in growing *S. sisymbriifolium*
2. Determine the distribution of total costs for each crop rotation

We hypothesize that the crop rotation containing only one year of *S. sisymbriifolium (SSI)*, Crop Rotation A, will obtain the least amount of additional costs and contain the greatest profit outcome. Contrarily, Crop Rotation C will contain the most additional cost and contain the least amount of profit. Crop Rotation B will have the second highest additional cost and profit.

Materials and Methods

We chose to evaluate the cost of each crop rotation from the stage of planting to the point of sale, using a simulation method to analyze the multiple crop rotations. Simulations are typical in the agriculture industry and used throughout to predict yields and greenhouse gases released. Agricultural Production Systems Simulator (APSIM) is one of many crop yield predictors (McCown et al., 1996). GreenAgSim is a simulation used to predict the amount of greenhouse gases released by agriculture production (Dumortier and Hayes, 2009). Our simulations are similar, but limited to costs and profit. The simulations were formed in Excel and analyzed by @Risk, a common business analysis simulation software.

The crop rotations were developed in Excel using a cost of production for irrigated Russet Burbank commercial potatoes with on farm storage; the average between the cost of production for irrigated spring feed barley and irrigated malting barley to establish a cost of production for all irrigated barley, and irrigated soft white winter wheat. In total four different cost of productions were used in each crop rotation in two different counties; Bingham county and Bonneville county. Overall, six different crop rotations were modeled and simulated, Crop Rotation A-C for Bingham county and the same for Bonneville county. While the Crop Rotations were explained in Chapter 3, a short definition is presented below.

Crop Rotation A is defined as the best possible outcome for inserting *SSI* into a potato rotation. That is, having to use one year of *SSI*, eradicating PCN, and then returning to regular potato production.

Crop Rotation B attended to the fact that *SSI* might not be successful in eradicating PCN in one year. Thus, including *SSI* in two separate growing seasons with only year apart.

Crop Rotation C also considered that *SSI* might not be successful in one year and includes two years of growing *SSI*. The years of growing *SSI* are three years apart though. This due to growers potentially not being able to afford growing *SSI* so close in years.

Stochastic Inputs

Each scenario had 7 stochastic input variables: potato yield, barley yield, wheat yield, potato price, barley price, wheat price, and potato seed price. Probability density functions (*pdf*) for the stochastic inputs were all found using a distribution fitting option in @Risk. The 'best fit' distribution was chosen based on a variety of factors. Best fit distributions were chosen based on: lowest chi-square, most linear quantile-quantile relationship, and most linear probability-probability relationship. A summary of all *pdf* inputs by scenario and county is provided in Table 4.2.

Table 4.2 Summary Statistics of Stochastic Inputs Used in the @Risk Model

Input	Function	Mean	Min	Max	Std. Dev.
Bonneville County Potato Yield	Triang(273,273,405.33)	315.50	276.00	376.00	26.89
Bonneville County Barley Yield	Triang(57.777,105,105)	89.83	68.00	104.00	9.66
Bonneville County Winter Wheat Yield	Triang(90.2,90.2,130.915)	103.23	91.00	122.00	8.33
Bingham County Potato Yield	Triang(283.64,409,409)	368.55	311.00	406.00	25.52
Bingham County Barley Yield	Triang(84.199,92.7,7,125.736)	100.57	88.00	118.00	7.74
Bingham County Winter Wheat Yield	Triang(89.587,122.8,122.8)	112.22	96.75	122.25	6.84
Idaho Potato Price	Loglogistic(5.5647,1.5671,3.309)	7.25	6.10	9.50	0.72
Idaho Barley Price	Loglogistic(5.83033,0.42419)	5.84	4.25	7.50	0.65
Idaho Winter Wheat Price	Loglogistic(6.31264,0.75152)	6.36	4.00	9.00	1.07

Sources: National Agriculture Statistics Service

University of Idaho, Department of Agricultural Economics and Rural Sociology

Yield

County-level yield data from 1996-2016 was obtained from the National Agriculture Statistics Service's (NASS). Not all years contained yield data for each commodity. Bingham county irrigated winter wheat yield was reported 1996-2001 and 2003-2007, barley yield was reported 1996-2016, but missed 2012 and 2013, potato yield was sufficiently reported from 1996-2016. Bonneville irrigated winter wheat yield was reported from 1996-2004 and 2009-2011, barley yield was sufficiently reported from 1996-2016, and potato yield was reported from 1996-2014. The function for Bonneville irrigated winter wheat yield was Triang(90.2,90.2,130.915), barley yield was Triang(57.777,105,105), and potato yield was Triang(273,273,405.33). The function for Bingham irrigated winter wheat yield was Triang(89.587,122.8,122.8), barley yield was Triang(84.199,92.7,7,125.736), and potato yield was Triang(283.64,409,409). Graphs of the *pdf*s for Bonneville and Bingham county's yields are presented in figures 4.1-4.6.

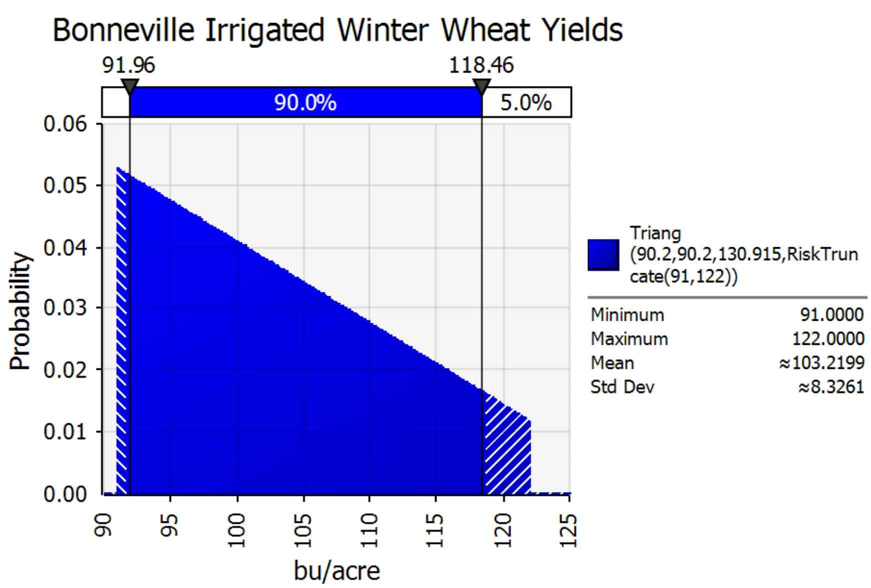

Figure 4.1 Estimated Probability Density Function for Bonneville County Irrigated Winter Wheat Yield

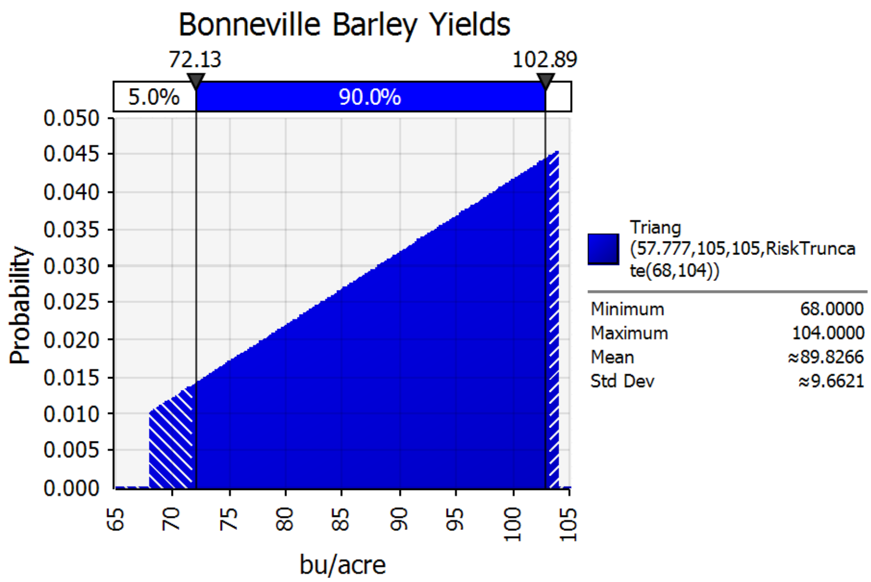

Figure 4.2 Estimated Probability Density Function for Bonneville County Barley Yield

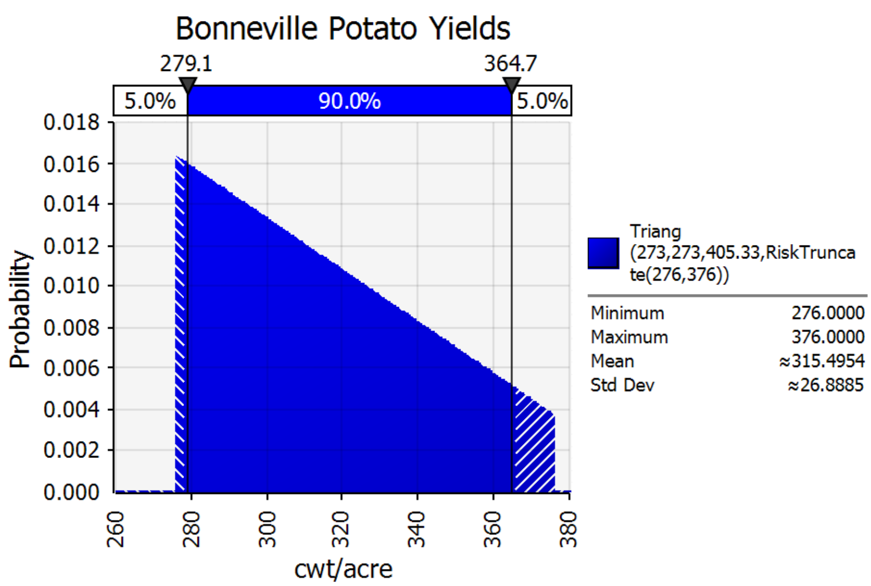

Figure 4.3 Estimated Probability Density Function for Bonneville County Potato Yield

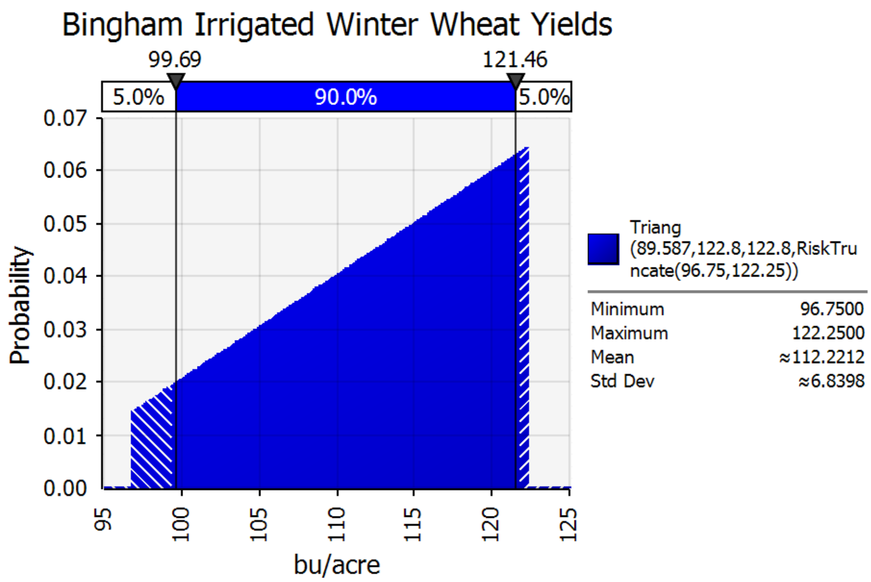

Figure 4.4 Estimated Probability Density Function for Bingham County Irrigated Winter Wheat Yield

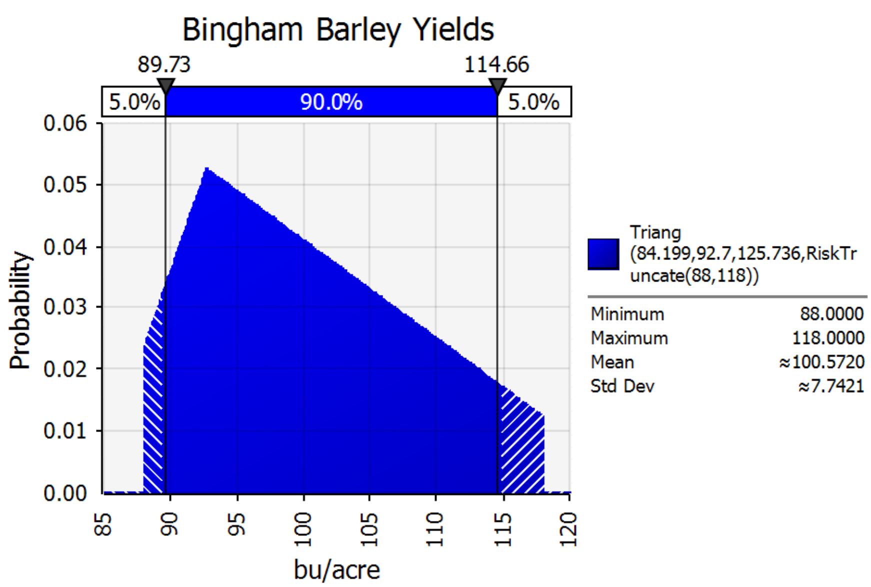

Figure 4.5 Estimated Probability Density Function for Bingham County Barley Yield

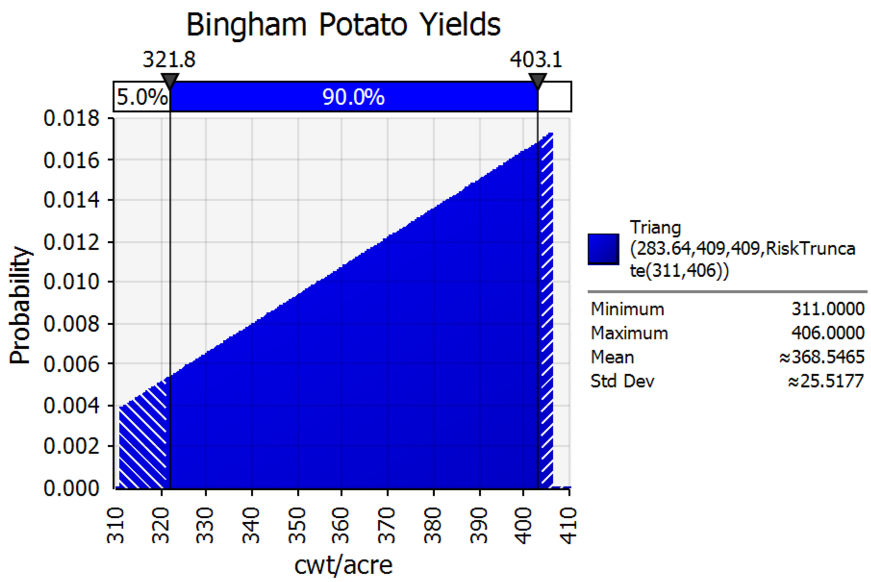

Figure 4.6 Estimated Probability Density Function for Bingham County Potato Yield

Price

*pdf*s for Idaho's commodity prices were found using NASS state-level data for 'price received' from the market years 2012-2016 on a monthly basis. The *pdf* for irrigated winter wheat price was Loglogisitc(6.31264,0.75152) and was truncated at historical extremes over the observed time period, with a minimum value of $4.00/bushel (bu) and a maximum value of $9.00/bu. The *pdf* for barley price was Loglogistic(5.83033,0.42419), truncated with a minimum $4.25/bu and a maximum of $7.5/bu. The *pdf* for potatoes was Loglogistic(5.5647,1.5671,3.309), truncated with a minimum of $6.10/hundredweight (cwt) and a maximum of $9.50/cwt. The graphs of the *pdf*s for Idaho commodity prices can be found in Figure 4.7-4.9.

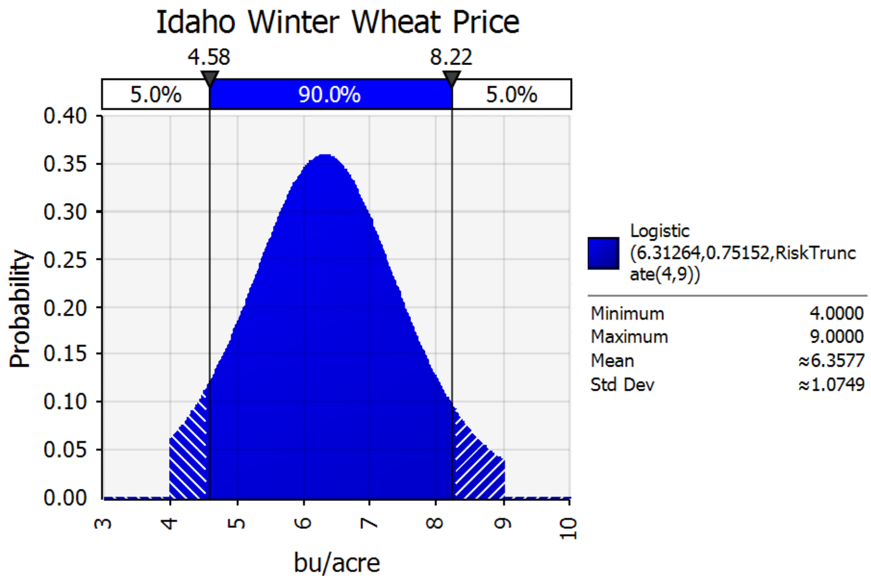

Figure 4.7 Estimated probability Density Function for Idaho Wheat Price

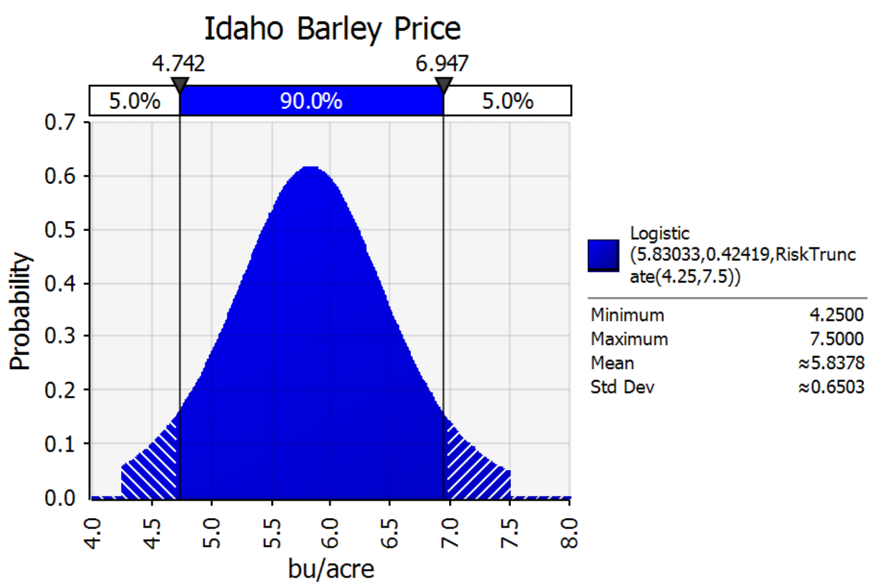

Figure 4.8 Estimated probability Density Function for Idaho Barley Price

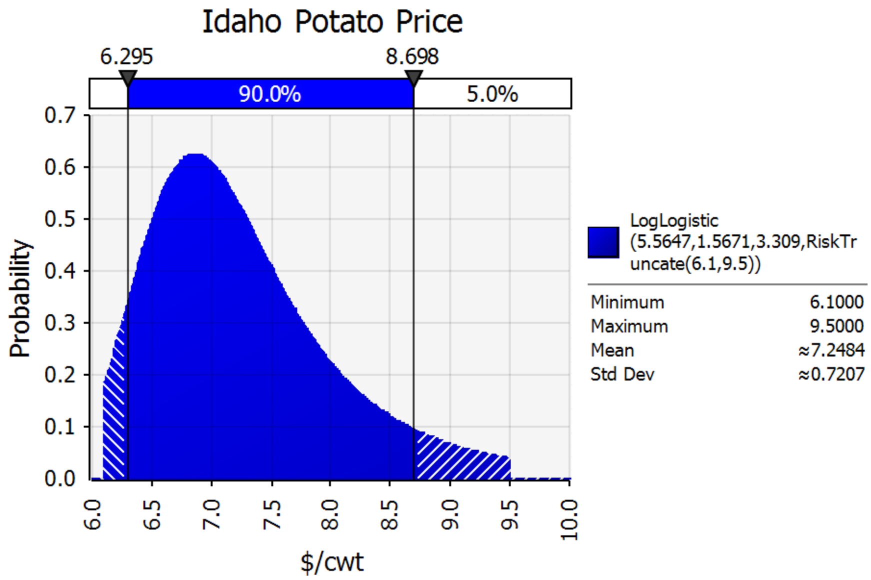

Figure 4.9 Estimated probability Density Function for Idaho Potato Price

To ensure the interactions between commodity prices and commodity yields variables were based on historically accurate correlations, correlations were calculated between all variables. By taking these interactions into account, it enabled the model to avoid combinations usually observed in the real world. The correlations were then transferred into a correlation matrix in @Risk that allowed for capturing of real world interactions among the variables. The correlation values between the six variables can be found in Table 4.3 and Table 4.4.

Table 4.3 @Risk Correlation Matrix for Bonneville County Production Crops

	Irrigated Winter Wheat Price	Irrigated Winter Wheat Yield	Barley Price	Barley Yield	Potato Price	Potato Yield
Irrigated Winter Wheat Price	1					
Irrigated Winter Wheat Yield	0.4238	1				
Barley Price	0.8615	0.5113	1			
Barley Yield	0.6214	0.6494	0.7020	1		
Potato Price	0.7773	0.5354	0.8121	0.7481	1	
Potato Yield	0.6898	0.7018	0.7951	0.6895	0.7987	1

Table 4.4 @Risk Correlation Matrix for Bingham County Production Crops

	Irrigated Winter Wheat Price	Irrigated Winter Wheat Yield	Barley Price	Barley Yield	Potato Price	Potato Yield
Irrigated Winter Wheat Price	1					
Irrigated Winter Wheat Yield	0.2085	1				
Barley Price	0.8615	0.3371	1			
Barley Yield	0.5021	0.7534	0.5863	1		
Potato Price	0.7773	-0.1147	0.8121	0.5135	1	
Potato Yield	0.6479	0.8202	0.8119	0.6583	0.6797	1

Results

Simulation outputs were classified in three separate ways: net present value of a normal potato rotation without PCN infestation and use of *SSI*, net present value of a rotation only containing barley and wheat, and net present value of potato rotations using *SSI* to eradicate PCN. Comparing the net present value of a potato rotation without *SSI*, and a rotation only growing wheat and barley to potato rotations containing *SSI* allowed us to analyze the economic impact of having to control for PCN in both Bingham and Bonneville county. As we initially thought, the mean net present value for a potato rotation without *SSI* was drastically higher than rotations including *SSI*, due to *SSI* rotations having a year without any profit. The rotations only growing wheat and barley achieved the lowest net present value in Bingham county, but not Bonneville county. Bingham county also had the highest net present value in all crop rotations compared to Bonneville county. Together both counties achieved Crop Rotation A with the highest mean net present value and Crop Rotation C with the lowest out of rotations implementing *SSI*. This section will present the final results for all crop rotations in both counties. Containing a comparison of summary statistics from all simulations conducted. All results are visible graphically as well as numerically.

Bonneville County

The net present value of a potato rotation without *SSI*, potato rotations integrating *SSI*, and a rotation only containing barley and wheat are summarized in Table 4.5. For Bonneville county, without the use of *SSI* the mean net present value equated to $3,535.50/acre, of which was drastically higher than Crop Rotations A-C and the wheat-barley rotation. Although this was expected because the rotation did not suffer a no profit year like the rest. Out of the rotations containing *SSI*, Crop Rotation A achieved the highest mean net present value at $2,757.18/acre. While Crop Rotation C resulted in the lowest at $1,751.26/acre. This was not a surprise due to Crop Rotation C having an additional year of *SSI* than Crop Rotation A. Expectedly, Crop Rotation B had a higher mean net present value than Crop Rotation C at $1,834.55/acre. Crop Rotation B and C both grew *SSI* two years and contained the same amount of years growing potatoes, wheat, and barley. The difference was Crop Rotation B grew *SSI* with only one gap year, where Crop Rotation C had three gap years. The rotation only containing wheat and barley derived the third lowest mean net present value at $1,928.93/acre.

Comparing the crop rotations containing *SSI* to the crop rotation without, we can find the economic impact of having to control for PCN. For only having to grow *SSI* one year (Crop Rotation A) it causes a grower a loss of $778.32/acre over fifteen years, equaling to $97,290.00 of loss per field. While having to grow *SSI* two years (Crop Rotation B and C) can produce a loss of $1,700.95/acre and $1,784.24/acre to a grower, equaling $212,618.75 and $223,030.00 on a field basis over fifteen years.

Comparing the crop rotation of only containing wheat and barley to the normal potato rotation, we can find the growers loss in profit due to PCN infestation. Only growing wheat and barley causes a loss of $1,606.57/acre, summing to a total of $200,821.25 of loss per field over a fifteen-year timeline.

Analyzing the coefficients of variation, it is observed that it follows a similar pattern as the mean net present value. With the rotation without *SSI* having the lowest at 17% and Crop Rotation C with the highest at 29% out of the rotations containing potatoes. The rotation only growing wheat and barley achieved the lowest overall at 15%; this could be due to the missing of potatoes. The coefficient of variation denotes the amount of risk associated with each crop rotation, the lower the percentage the less risk involved. Crop Rotation A yielded the lowest coefficient of variation out of the crop rotations containing *SSI* at 21%. Crop Rotation B was closer to Crop Rotation C than A with a coefficient of variation at 27%.

The rotation only containing wheat and barley had the lowest overall coefficient of variation, but also the third lowest mean net present value. Crop Rotation A was 6% higher in risk than the wheat-barley rotation, but $828.25/acre more profitable. Crop Rotation B was 12% higher in risk and $94.38/acre less profitable and Crop Rotation C was 14% higher in risk, but less profitable by $221.51/acre. With only a small difference in risk and large difference in dollars per acre, Crop Rotation A could be feasible. Figure 4.10-13 display the distribution of net present value for each crop rotation.

Table 4.5 Bonneville County Net Present Value

	Normal Potato Rotation	Wheat Barley Rotation	Crop Rotation A	Crop Rotation B	Crop Rotation C
Mean ($/acre)	3,535.50	1,928.93	2,757.18	1,834.55	1,751.26
Min ($/acre)	1,821.61	913.56	1,041.48	411.49	411.15
Max ($/acre)	6,067.30	2,986	5,014.00	3,697.02	3,599.12
Std. Deviation	628.90	297.78	584.87	505.48	509.07
Coeff. of Var.	17%	15%	21%	27%	29%
Lower 5%	2,568.00	1,446.00	1,870.00	1,064.00	983
Upper 95%	4,641.00	2,425.00	3,766.00	2,720.00	2,654.00

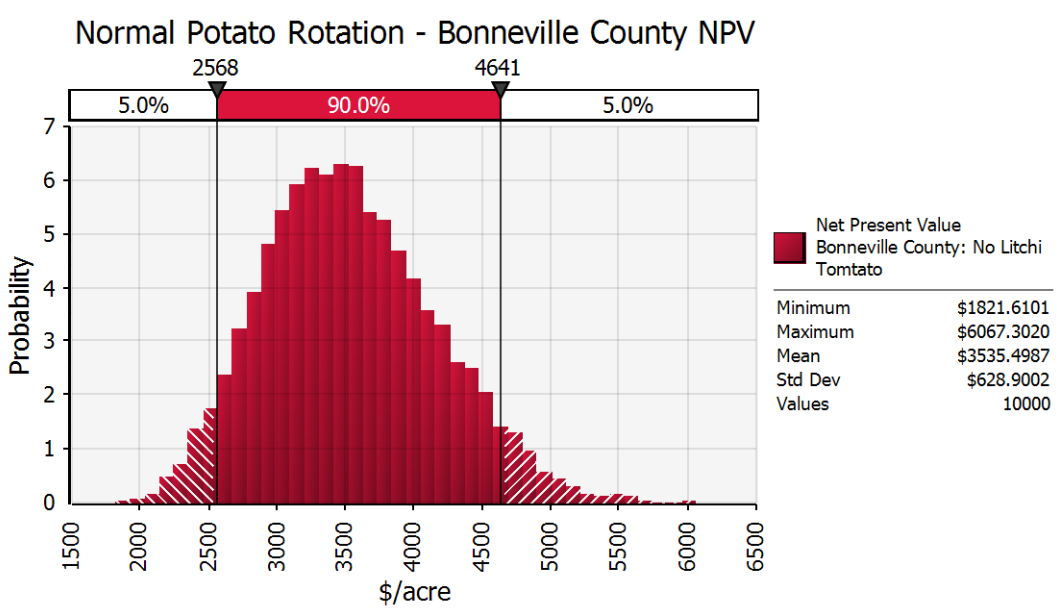

Figure 4.10 Bonneville County Net Present Value Distribution for Normal Potato Crop Rotation

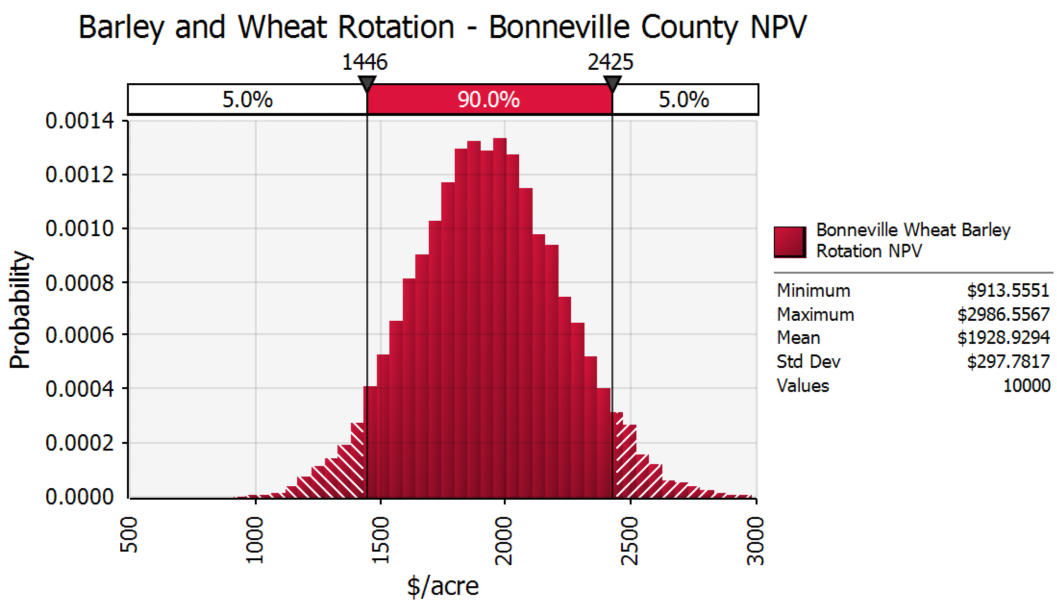

Figure 4.11 Bonneville County Net Present Value Distribution for Barley and Wheat Crop Rotation

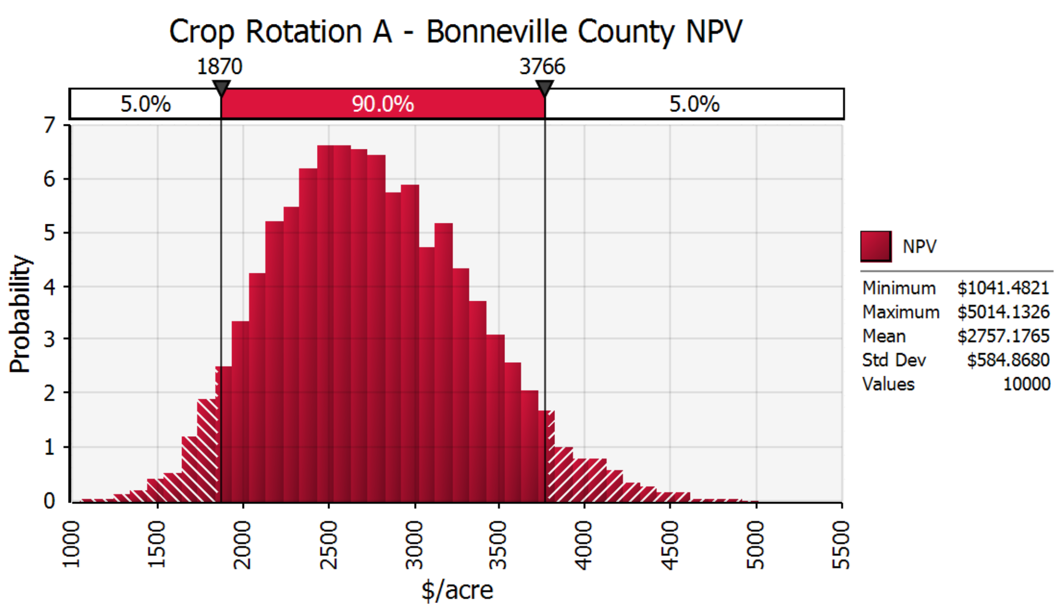

Figure 4.12 Bonneville County Net Present Value Distribution for Crop Rotation A

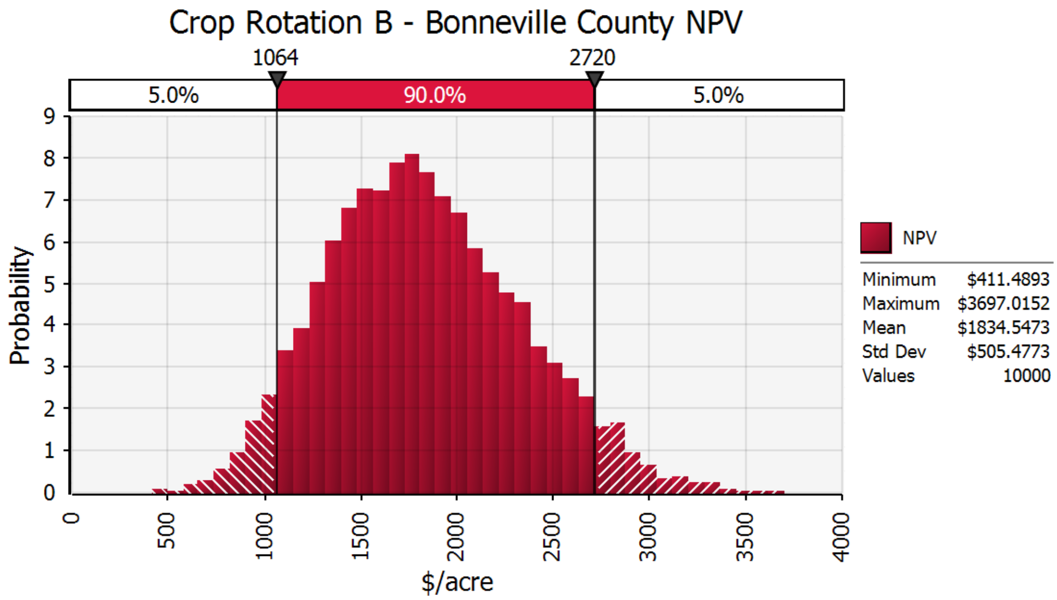

Figure 4.13 Bonneville County Net Present Value Distribution for Crop Rotation B

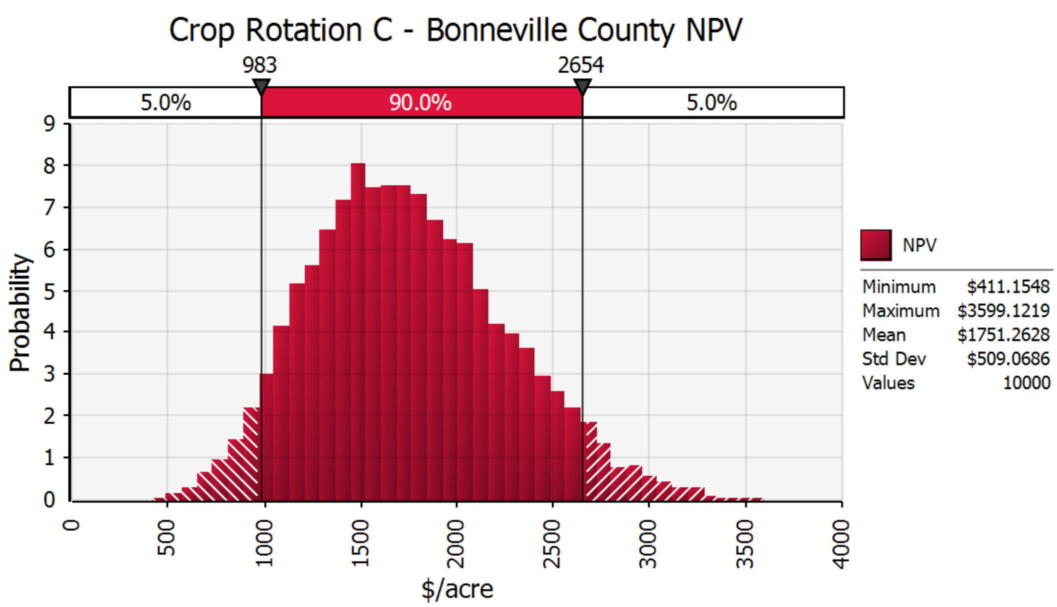

Figure 4.14 Bonneville County Net Present Value Distribution for Crop Rotation C

Bingham County

Table 4.6 summarizes the mean net present value, standard deviations, and upper and lower confidence intervals for the normal potato rotation not containing *SSI*, crop rotation only containing wheat and barley, and Crop Rotation A-C for Bingham county. As a result of Bingham county producing higher average yields than Bonneville county in all three crops grown in our rotations, mean net present value is higher in each crop rotation scenario. Even though cost per acre is slightly higher in Bonneville county. Expectedly, the crop rotation not containing *SSI* achieved the highest mean net present value than all the other crop rotations at $4,705.89/acre. Similar to Bonneville county, out of the crop rotations containing *SSI* Crop Rotation A had the highest mean net present value at $3,822.56/acre and Crop Rotation C once again had the lowest at $2,557.52/acre. Crop Rotation B obtained a mean net present value of $2,700/acre. Contrarily, the rotation only containing barley and wheat achieved the lowest mean net present value at $2,437.36/acre. The same crop rotations were used for both counties, thus the same theory used to describe why Crop Rotation A contained the highest mean net present value and Crop Rotation C achieved the lowest in Bonneville county will also be used for Bingham county.

Analyzing the mean net present values, we can derive the economic impact on a grower for having to control for PCN. If a grower was able to eradicate PCN in one year and only plant *SSI* once (Crop Rotation A) they would face a loss of $883.33/acre over a fifteen-year period, equivalent to $110,416.25 in loss off of one field. If a grower was unable to eradicate PCN in one year, but could plant back to *SSI* as soon as possible (Crop Rotation B) they would suffer a loss of $2,005.57/acre over a fifteen-year period, causing $250,696.25 in loss off of an individual field. A grower might not be able to plant back *SSI* as soon as possible and must wait three years before so (Crop Rotation C) would accumulate a loss of $2,148.37/acre over a fifteen-year period, equal to $268,546.25 in loss off of a field.

Comparing the rotation only containing wheat and barley to the normal potato rotation, we can derive the loss a grower faces when infested with PCN. Only growing wheat and barley will give a grower a loss of $2,268.53/acre, equating to $283,566.25 of loss of an individual field, over a fifteen-year period.

Bingham county resulted in much lower coefficients of variations than Bonneville county. With the rotation only growing wheat and barley having a value of 12%, the rotation not containing *SSI* at 13%, Crop Rotation A at 15%, Crop Rotation B at 18%, and Crop Rotation C at 19%. While Crop Rotation A achieved the lowest risk out of all the rotations containing *SSI*. surprisingly, the crop rotation only containing wheat and barley obtained the lowest risk of them all in Bingham county.

In Bingham county, the wheat and barley rotation achieved the lowest coefficient of variation along with the lowest mean net present value. For Bingham county, Crop Rotations A-C were closer in risk to the wheat barley rotation than Bingham county. Crop Rotation A was 3% higher in risk, but $1,385.20/acre more profitable, Crop Rotation B was 6% higher in risk and more profitable by $262.96/acre, and Crop Rotation C was 7% higher and more profitable by $120.16/acre. With lower differences in risk and higher profit margin than Bonneville county, integrating *SSI* in Bingham county could be more feasible to a potato grower for all crop rotations. Figure 4.14-17 present the distribution of net present value for each crop rotation.

Table 4.6 Bingham County Net Present Value

	Normal Potato Rotation	**Wheat Barley Rotation**	**Crop Rotation A**	**Crop Rotation B**	**Crop Rotation C**
Mean ($/acre)	4,705.89	2,437.36	3,822.56	2,700.32	2,557.52
Min ($/acre)	2,627.35	1,441.94	2,079.65	1,129.02	846.73
Max ($/acre)	7,270.76	3,574.71	6,421.61	4,488.92	4,061.57
Std. Deviation	624.61	296.61	572.69	501.78	487.01
Coeff. of Var.	13%	12%	15%	18%	19%
Lower 5%	3,719.00	1,952.00	2,914.00	1,916.00	1,788.00
Upper 95%	5,771.00	2,934.00	4,800.00	3,554.00	3,392.00

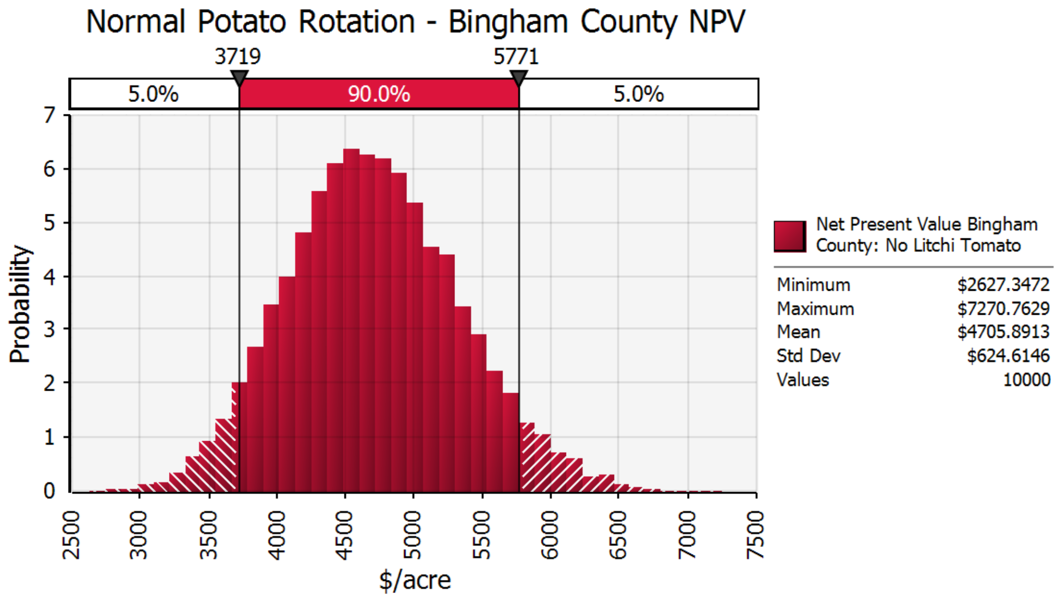

Figure 4.15 Bingham County Net Present Value Distribution for Normal Potato Crop Rotation

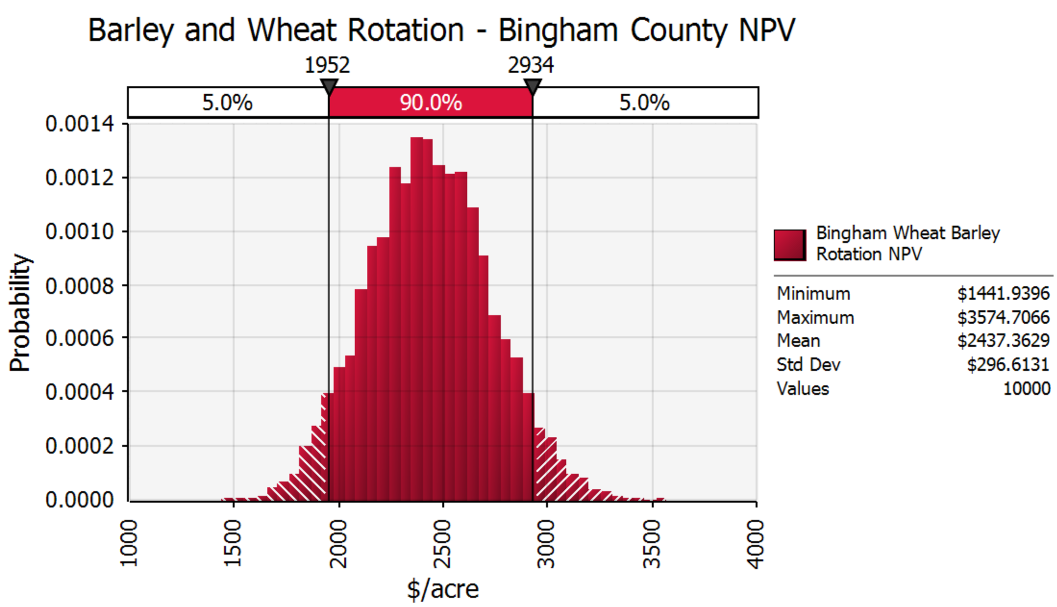

Figure 4.16 Bingham County Net Present Value Distribution for Barley and Wheat Crop Rotation

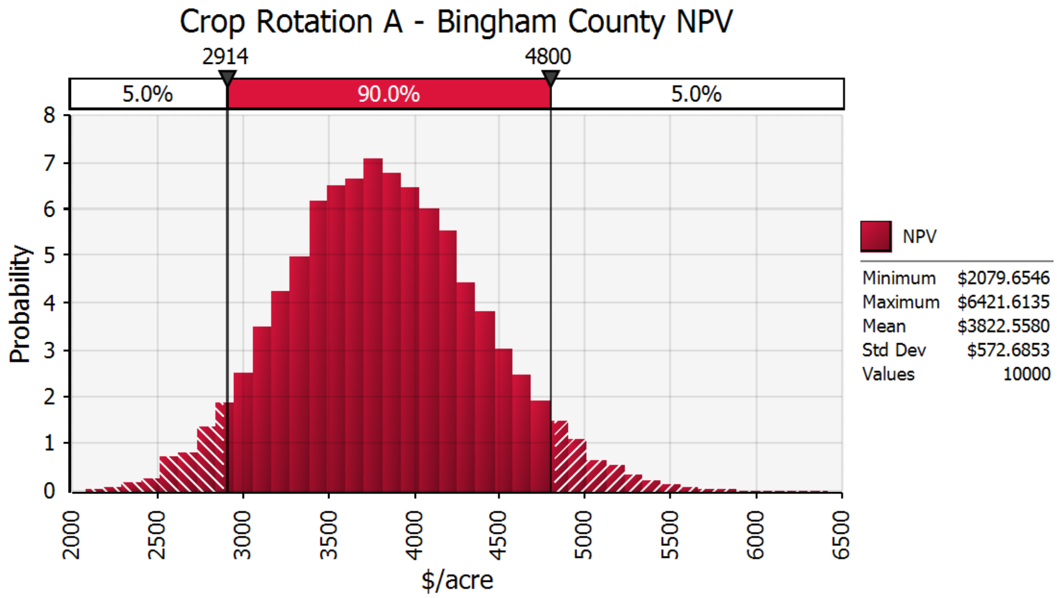

Figure 4.17 Bingham County Net Present Value Distribution for Crop Rotation A

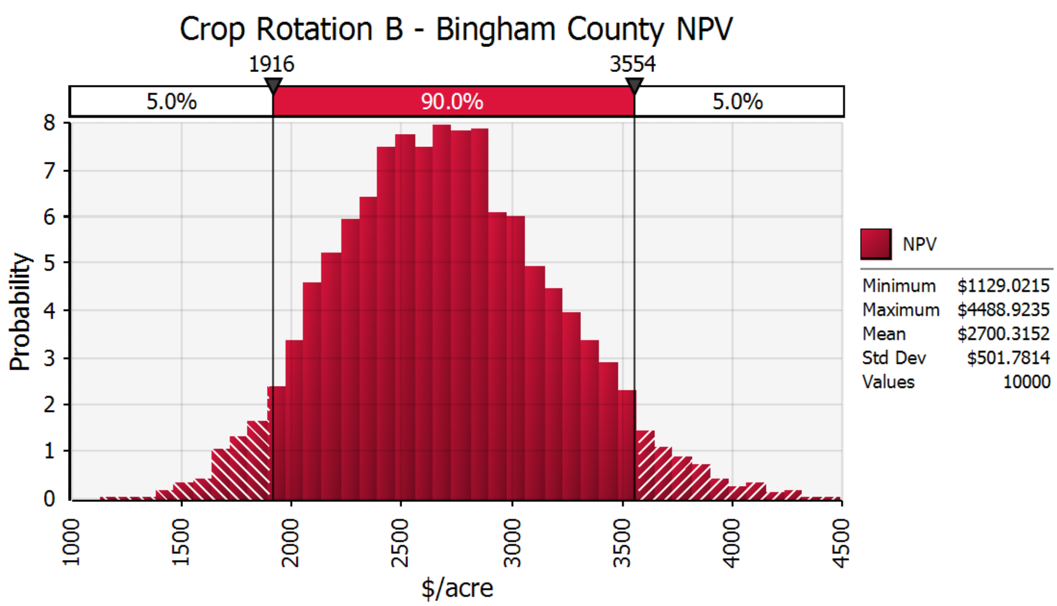

Figure 4.18 Bingham County Net Present Value Distribution for Crop Rotation B

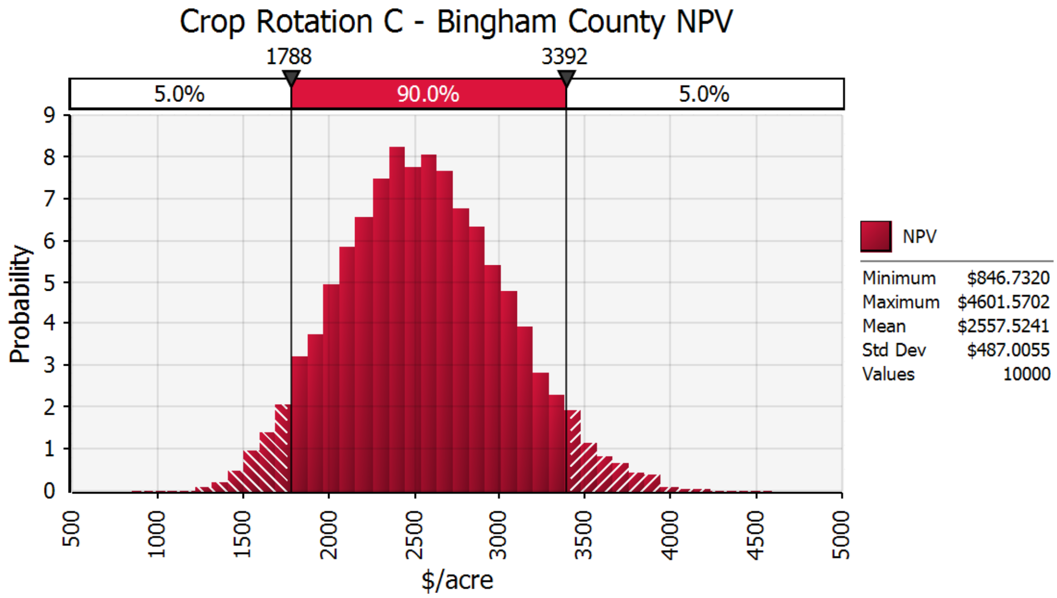

Figure 4.19 Bingham County Net Present Value Distribution for Crop Rotation C

Discussion

The first considerable finding is that integrating *SSI* into a crop rotation will undoubtedly increase a grower net present value that is infested with PCN in Bingham county, but not necessarily Bonneville. Currently in the infested areas growers predominately plant barley and wheat. From the simulations results, this rotation achieved the lowest mean net present value in Bingham county, with a value of $2,437.36/acre. In Bonneville county this rotation obtained a higher mean net present value then all rotations implementing *SSI* except for Crop Rotation A at a value of $1,928.93/acre. The lowest mean net present value of a rotation containing *SSI* in Bingham county was $2,557.52.52/acre, summing to a difference of $120.16/acre. In Bonneville county, the only crop rotation containing *SSI* that had a higher mean net present value than the wheat-barley rotation achieved a value of 2,757.18 coming to a difference of $828.25.

The second important finding is that by implementing *SSI* into a crop rotation a grower is still able to produce a considerable profit in Bingham county. Even with the cost of $515.65/acre for growing *SSI*. In Bingham county, each crop rotation resulted in a mean net present value greater than $2,500/acre summing to $312,500 of profit over a fifteen-year time period from one field. In Bonneville county, only when *SSI* is successful in the first year will the grower gain profit compared to their current rotations. However, the other crop rotations still made a feasible amount of profit with them all obtaining a mean net present value higher than $1,750/acre equating to $218,000 over a fifteen-year time period from an individual field.

The third major finding is the amount of profit loss a potato grower is attaining due to PCN infestation. Without the ability to grow potatoes and the ability to grow alfalfa, due to MeBr contamination, growers are forced to only grow barley and wheat. Comparing the barley and wheat rotation to the normal potato rotation in Bonneville county, the mean net present value for the normal potato rotation was 45.45% higher than the wheat and barley rotation. In Bingham county the normal potato rotation was 48.21% higher than the wheat and barley rotation.

The last important finding is the risk and profit difference between the wheat-barley rotation and Crop Rotations A-C in Bingham county and Crop Rotation A in Bonneville county. The difference in risk was relatively low in both counties, but was more minimal in Bingham county. In Bonneville county, the difference in risk was 6%, but was considerably more profitable. In Bingham county, Crop Rotation B and C was higher in risk than the wheat-barley rotation by 6% and 7% and more profitable. Crop Rotation A was 3% higher in risk and the most profitable. With each of the respective crop rotation having low differences in risk and higher mean net present value compared to the wheat-barley rotation integrating *SSI* could be feasible for the regions potato growers.

Limitations of Model

Combined with the major findings of this study are some limitations of the model. Due to limited data available, we were unable to use irrigated barley yield as my barley variable. Irrigated barley yield would've been a more relevant variable than all barley (irrigated and dryland) when constructing a crop rotation around potatoes since potatoes are only grown under irrigation. However, after the industry expert interviews and learning that there is very limited dryland barley in the respected counties we felt comfortable enough to use the all barley data set. Contrary to barley there is a considerable amount of dryland wheat in both counties. Thus, we were forced to use a limited data set for irrigated winter wheat. Only containing wheat yields as early as 2011 for Bonneville county and 2007 for Bingham county. When observing the irrigated winter wheat yield data set it is observed that although the data maybe possibly be outdated, the yields are similar to yields produced today, reaching as high as 122bu/acre, making the data set viable.

When constructing total costs for each year in all crop rotations it became apparent that if we used total ownership costs every year was going to have a negative profit. Therefore, we decided to use total operating costs for the simulated crop rotations. Total ownerships costs included variables that deemed unnecessary, with such variables as equipment insurance, general overhead, and management fee.

Also, total costs are constant throughout each crop rotation. This is due to the producers paid index fluctuating inconsistently throughout time. In 2008 the producer paid index decreased from 90.0 to 87.3 in 2009 (USDA, 2018). Then climbed to 110.2 in 2015 and has decreased to 105.4 in 2016. Agriculture products are also inconsistent and are capable of falling and rising in price through the products market life. As portrayed when we assembled pesticide prices, not all growers are given the same price.

Chapter 5 Conclusion

SSI seems to be the only logical solution to eradicating PCN from Bingham and Bonneville county. Currently the only control method is the use of the fumigate DCP, of which its effectiveness is quantitatively low, with APHIS and ISDA just now releasing fields that were quarantined in 2006. In Europe, *SSI* has proven to successfully control PCN in areas that don't support the growth of *SSI* as much as southeastern Idaho. While there are still many obstacles before *SSI* can be grown at a commercial size, this is typical for even new varieties of commodities that have been grown for a century. The question isn't if *SSI* will be introduced as a control method, but when. We hope that this research has provided some meaningful findings that can support the effort.

Important Findings and Implications

Findings from this study offer purposeful results to the Idaho potato industry. More importantly it displays economic analysis for the production of *SSI* to the Idaho potato grower.

The first important finding is that based on already conducted studies, *SSI* has significant potential in eradicating PCN from Bonneville and Bingham county. Without eradication Bonneville and Bingham county will never be able to export potatoes to Japan, a major purchaser of Idaho potatoes, along with the respected counties unable to export to Mexico and Canada. Many fumigate controls have been used and failed, including the reintroduction of MeBr of which caused cattle poisoning. If eradication is not achieved fields can be out of potato production for as long as thirty years and continue to cause economic loss not only to the grower, but indirectly affect the community. In greenhouse settings, *SSI* has proven to cause 99% PCN population reduction. Contributing to potential eradication of PCN in one growing season.

Another important finding is the cost of production derived in this study for *SSI*. A cost of production for *SSI* has never been estimated in the United States and it is important for the grower to know these costs before implementing the trap crop into their rotation.

While these findings are important, they are not sufficient. A proper estimation of crop rotations net present value is necessary. By using cost of productions, historical price and yield data, and @Risk modeling software, we have been able to estimate the net present value of crop rotations implementing *SSI*. The distribution of mean net present value for each crop rotation has presented that financial gain still can be accomplished conducting a crop rotation including *SSI*. In addition, if *SSI* is ineffective in eradicating PCN in one year and an additional year of *SSI* is required, a grower can still obtain a considerable profit in Bingham county, While in Bonneville *SSI* must be effective in the first year in order for a grower to see any additional profit. However, the rotations deriving a lower mean net present value than the wheat-barley were only slightly lower and could still be feasible options for growers. When comparing coefficients of variations with crop rotations implementing *SSI* and the wheat-barley rotation growers are using currently in infest fields. The low difference in risk and high difference in profit is too much to not consider for the crop rotations attaining a higher mean net present value than the wheat-barley rotation and could help influence growers to contributing in a *SSI* eradication program.

Lastly, While PCN has been established in Bonneville and Bingham county since 2006, little work has been conducted on the economic impact it has had on the regions potato growers. In this study we presented these results and have shown that PCN is causing greater than 45% profit reduction over a fifteen-year time period for a potato grower. With such a drastic reduction this could potentially lead to growers foreclosing.

Further Research

While this study provides a comprehensive insight into the possibilities of implementing *SSI* into crop rotations, there are further areas for research. The foundation of this research of done on many assumptions. As more relative data becomes available similar studies can replace these assumptions with real world results.

Data from field trials conducted in the infested regions could help further develop crop rotations. Knowing exactly what herbicides can be used would construct a more reliable cost of production for *SSI* and be beneficial to growers. Yield data for irrigated crops on a county basis would make predicting net present value more efficient. While these are just some suggestions on further research, we hope that this study has laid a sturdy base for investigations conducted in the future.

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