# CONCEPTUAL DESIGN FOR SWITCHGRASS PRODUCTION SIMULATION IN A BIOMASS SUPPLY CHAIN USING GLADIS 2.0

By

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# CONCEPTUAL DESIGN FOR SWITCHGRASS PRODUCTION SIMULATION IN A BIOMASS SUPPLY CHAIN USING GLADIS 2.0

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Abstract: Switchgrass (Panicium vigratum) has been heavily evaluated as a model crop for producing cellulosic biomass. The lengthy productive lifetime of stands and longevity in non-ideal conditions makes it an ideal option for sustainable biomass production. Several studies have been evaluated the economic feasibility of growing switchgrass as a bioenergy crop, however these models lack the specificity needed for individual producers to evaluate possible biomass production strategies with an easy to use decision tool. The expansion of Oklahoma State's Geospatial Logistics and Agricultural Decision Integration System (GLADIS) meets this need by identifying and mapping crop production parameters and existing agricultural economic and engineering models into a module based simulation framework. In order to successfully utilize module based simulation of crop production, an overarching module mapping was created which will be the base simulation framework that users can work with in the GLADIS platform. A model was also created, from several existing farm machinery cost estimation models, that will allow producers the ability to evaluate the specific machinery combinations needed to complete each field process.

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# CHAPTER I

## INTRODUCTION

### Background

Oklahoma State University's Geospatial Logistics and Agricultural Decision Integration System (GLADIS) was originally designed to model and conduct sensitivity analysis for the logistics of a Biomass Supply Chain (BSC) driven by Eastern Red Cedar (Craige et al., 2013). The tool was developed to map prospective biomass refinery locations and develop logistical strategies to meet the sourcing needs of those refineries. The redesign of the GLADIS tool, funded by the South Central Sun Grant Initiative, aims to develop a user friendly online interface, which can aid prospective producers in making the decision to produce and harvest switchgrass as a biomass. This expansion maps possible production scenarios and calculates the associated costs with each to generate individualized strategies for producers to implement, to create more sustainable returns.

This thesis identifies necessary production parameters for evaluating the production processes associated with growing and harvesting switchgrass, and implements existing agricultural models to estimate production process costs to aid producers in assessing the viability of growing switchgrass for their individual operations.

Producers will have access to the system through a web-based interface, where they can input their specific costs and resource constraints. In the likely scenario where a user does not have sufficient information on costs and constraints, GLADIS uses predefined distributions and data points for estimating process costs. This will enable the producer to evaluate multiple scenarios, with factor inputs production methods varying, to more accurately model specific combinations of resource constraints and operations strategies. The system calculates the total cost of delivering stacked bales or tons of biomass to the edge of the field, while providing the user with detailed reports for in-depth sensitivity analysis for their respective operations. The reports generated will give a detailed estimate of the costs and possible returns, which they could take to a loan officer or investors in order to raise capital for their planned operation.

## Problem Statement

The Renewable Fuel Standard (RFS) Program, created by the Energy Policy Act of 2005 (EPAct) and then further expanded by the Energy Independence and Security Act of 2007 (EISA), establishes yearly production volume targets for renewable fuels. The RFS was implemented to decrease the U.S.'s reliance on nonrenewable fuel sources and encourage the production and use of renewable fuel, which would ideally reduce or replace petroleum-based fuel sources. The RFS has four categories of renewable biofuels: biomass-based diesel, cellulosic biofuel, advanced biofuel, and total renewable fuel. The volume standard for cellulosic biofuel increases to sixteen billion gallons by 2022 (Schnepf &Yacobucci, 2010).

Switchgrass (Panicium virgatum) is a hardy and durable plant that can be harvested for ten or more years if stand establishment is successful. This stand longevity in non-ideal growing conditions makes switchgrass attractive to producers and policy makers as a sustainable option for cellulosic biofuel production.  However, in producing switchgrass as a feedstock for cellulosic biofuel, multiple production parameter costs have to be estimated so that producers can make well-informed decisions on whether or not to produce switchgrass and the lowest cost methods of production.

Research has been done to estimate the costs of producing switchgrass (Epplin, 1996; Duffy & Nanhou, 2002; Sokhansanj et al, 2009). However, these previous studies calculate total production cost by summing each individual production process cost - e.g., seeding, nutrient management, harvesting, and biomass transportation which are defined from previous studies as a single value estimated from generalized production strategies. This is a problem because these methods are not easily adaptable to an individual producer's resources constraints and production methods, which would result in a biased estimation of total cost for an individual's production strategy. Software programs have also been designed to provide production budgets to switchgrass producers (Griffith, Epplin, and Redfearn, 2014) and aid interested parties in assessing the feasibility of certain types of biorefineries and processing methods (Holcomb and Kenkel, 2008). However, there is not a widely accessible, user-friendly program that simulates production processes for a Biomass Supply Chain (BSC), nor which provides in depth cost analysis and generates detailed reports to aid producers in the production decision.

For prospective producers, analyzing cost for an individual operation is necessary to evaluate potential switchgrass economic returns. Maximizing returns for a new or additional feedstock in an operation requires the planning and implementation of precise production strategies. This means that simple spreadsheet production budgets or estimations from generalized extension factsheets may not be sufficient in providing the necessary risk analysis and scenario evaluation to aid individual producers in specific production planning.  The research question then becomes: How can individual switchgrass producers easily evaluate production methods and assess risk potential among multiple parameters to minimize total production cost, and thereby operate efficiently in bio-energy supply chains for the production of cellulosic ethanol?

## Objectives

The objective goal of this research was to develop a, user-friendly online modeling, platform that will allow both producers and researchers to evaluate a complex Biomass Supply Chain (BSC), while incorporating risk assessment to aid producers in making production decisions for their individual operations.

The specific objectives of this research are to:

1. Conceptually develop the design of a BSC for switchgrass production to use in OSU's Geospatial Logistics and Agricultural Decision Integration System (GLADIS).
2. Identify the parameters associated with growing and harvesting switchgrass, and integrate existing production process cost estimation models, to be incorporated in GLADIS for improved risk and sensitivity analysis potential.

# CHAPTER II

## REVIEW OF LITERATURE

Assessing the viability of individual producers adopting switchgrass production into pre-existing operations is critical to developing sustainable biomass supply chains. The following chapter lays out the specific research that has been reviewed in order to establish a baseline of; why switchgrass grown for bioenergy production can help meet national renewable fuel mandates, why it has been continuously studied as a model bioenergy crop, in which climates do different ecotypes thrive, expected and historical yields for different varieties and regions, how to use generally accepted methods to maximize biomass yield, and methods for estimating production costs.

### Overview of Renewable Fuel Standard

The Renewable Fuel Standard (RFS) program was created under the Energy Policy Act of 2005 (EPAct), which replaced the Clean Air Act (CAA). The program was further expanded by the Energy Independence and Security Act of 2007 (EISA). The EPA, along with the USDA, implemented the RFS, which placed mandates on the total volume of renewable fuel produced to replace or reduce the quantity of petroleum based transportation fuel, heating oil, or jet fuel. The RFS has mandates for each of the four categories; biomass-based diesel, cellulosic biofuel, advanced biofuel, and total renewable fuel.

Under EISA, the program extended mandates out to 2022 and boosted long term production volume requirements to 36 billion gallons. Just under half of that requirement is expected to come from the production of cellulosic biofuel at 16 billion gallons by 2022 (EPA, 2020). In order to be in compliance with the RFS, renewable fuels must have a reduction in Green House Gas (GHG) emissions compared to a 2005 petroleum baseline.

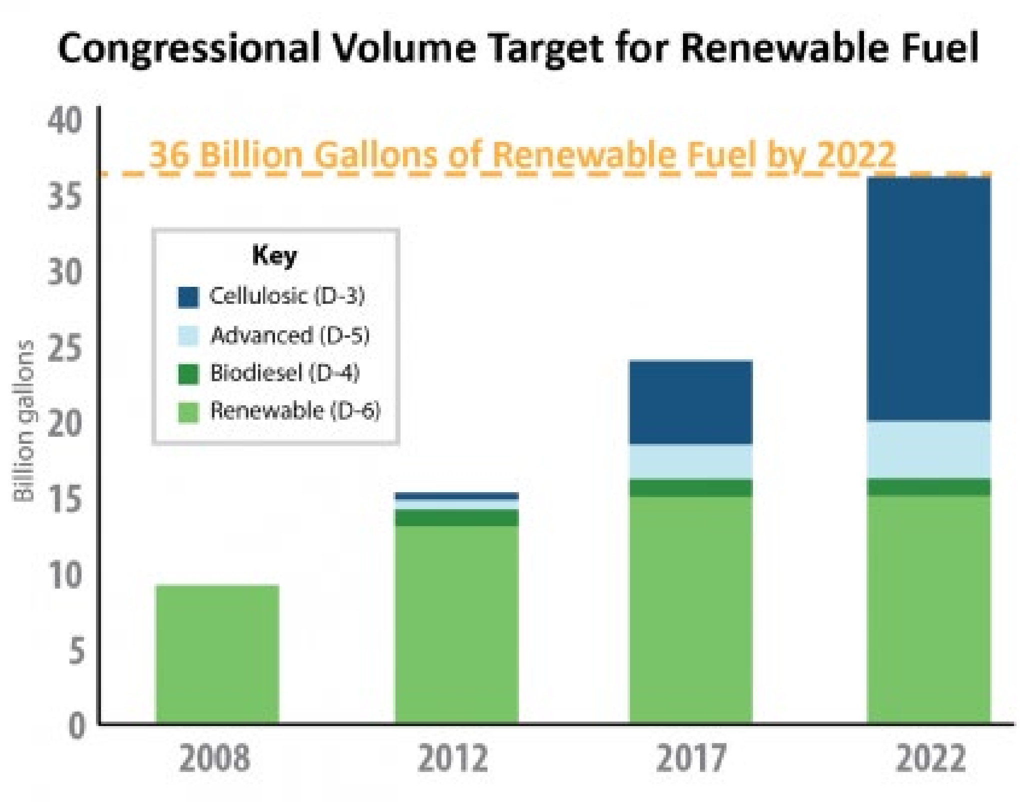
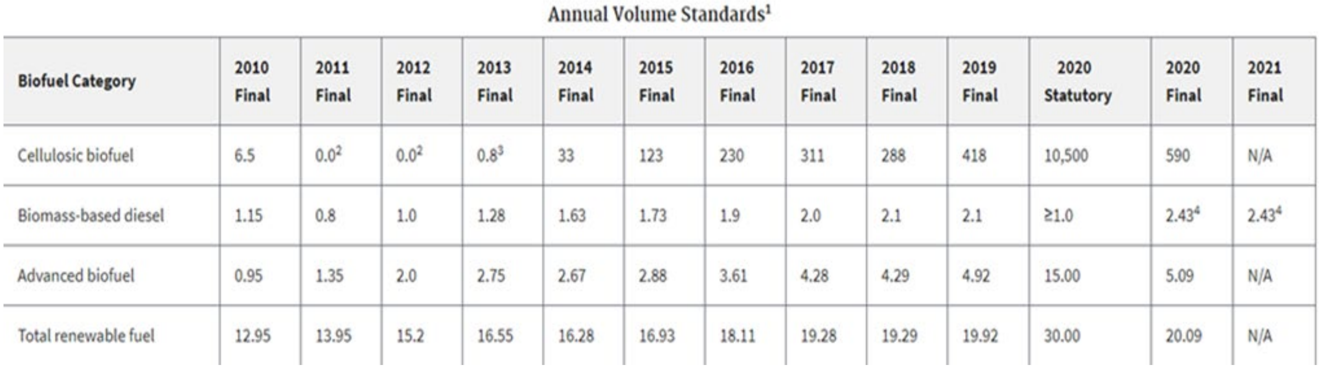


**Figure 2.1**: Renewable Fuel Standard Mandated Volume by Year Chart (EPA, 2020)

While the production volumes are increasing at roughly the same rate as the other categories, production volumes are not adequate to satisfy the initial projections of cellulosic biofuel which account for almost half of the total production requirements in 2022. There is a clear deficit between cellulosic biofuel production volumes and the production volumes in the other two categories. This demonstrates the increased need to make cellulosic biofuel production more efficient and incentivize current and potential producers to enter the market. The figure below depicts the annual volume standards and the final production amounts from 2010-2019 (EPA, 2020). Cellulosic biofuel is notated in millions of gallons while the biomass based diesel and advanced biofuels are notated in billions of gallons produced.



Annual Volume Standards[1]

| Biofuel Category | 2010 Final | 2011 Final | 2012 Final | 2013 Final | 2014 Final | 2015 Final | 2016 Final | 2017 Final | 2018 Final | 2019 Final | 2020 Statutory | 2020 Final | 2021 Final |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cellulosic biofuel | 6.5 | 0.0[2] | 0.0[2] | 0.8[3] | 33 | 123 | 230 | 311 | 288 | 418 | 10,500 | 590 | N/A |
| Biomass-based diesel | 1.15 | 0.8 | 1.0 | 1.28 | 1.63 | 1.73 | 1.9 | 2.0 | 2.1 | 2.1 | ≥1.0 | 2.43[4] | 2.43[4] |
| Advanced biofuel | 0.95 | 1.35 | 2.0 | 2.75 | 2.67 | 2.88 | 3.61 | 4.28 | 4.29 | 4.92 | 15.00 | 5.09 | N/A |
| Total renewable fuel | 12.95 | 13.95 | 15.2 | 16.55 | 16.28 | 16.93 | 18.11 | 19.28 | 19.29 | 19.92 | 30.00 | 20.09 | N/A |

**Figure 2.2**: Annual Volume Standards thru 2021 RFS Mandate (EPA, 2020)

## Second Generation Biofuels

The split between first and second generation biofuels is based on the type of feedstock used. First generation biofuels typically use sugars, grains, and seeds that are easy to process as feedstocks. Second generation biofuels utilize lignocellulosic biomass, which include crops or forestry residue and whole plant biomass (Naik et al., 2010). Dedicated energy crops from perennial forage crops, such as switchgrass and miscanthus, have the potential to dominate the second generation biofuels due to low water, low nutritional requirements, and adaptability to harsh environmental climates (Wright and Turhollow, 2010). However, these crops usually take longer to establish and require a longer time commitment from land owners, which could dissuade potential producers and bio refinery owners from incorporating these feedstocks into their enterprises.

In 1991, the Bioenergy Feedstock Development Program (BFDP), funded by the Department of Energy at Oak Ridge National Laboratories, refocused their herbaceous crops research on switchgrass, as a high yielding perennial grass. The BFDB had previously conducted research to develop fast growing trees and herbaceous crops in order to evaluate potential crop residues as sources for renewable energy since 1978. McLaughlin et al (1999) reported that switchgrass, a warm season prairie grass, was chosen as the model energy crop because of its high yield potential, compatibility with conventional farming practices, and increased soil conservation and quality

## All About Switchgrass

The US Department of Energy in 1991 identified switchgrass as the leading dedicated energy crop due to its sustainability in a myriad of environments and its comparative production potential against other perennial grasses and conventional crops (Wright and Turhollow, 2010). Although switchgrass has been historically dispersed across North America, many commercial varieties have been developed to thrive in specific regions and growing climates. These varieties can be categorized as being more suitable to three regions; southern, mid, and northern regions. These regions and varieties have been selected based on the day length for each region during the growing season (Blade Energy Crops, 2009).

The northern region is depicted in the figure below as the light blue shaded region, the mid is depicted as the light green shaded region, and the southern region is the dark green shaded region on the map. Switchgrass is divided into two different ecotypes lowland and upland. Lowland switchgrass typically has taller stands, coarser leaves, and has stronger bunch type growth. This usually leads to a higher yielding crop that can grow rapidly without specific crop management. The lowland type grows well in floodplain regions with higher moisture availability. The upland types do not grow as rapidly as its counterpart due to shorter stands, however they are typically more tolerant of the cold, which is better suited for the colder northern regions.

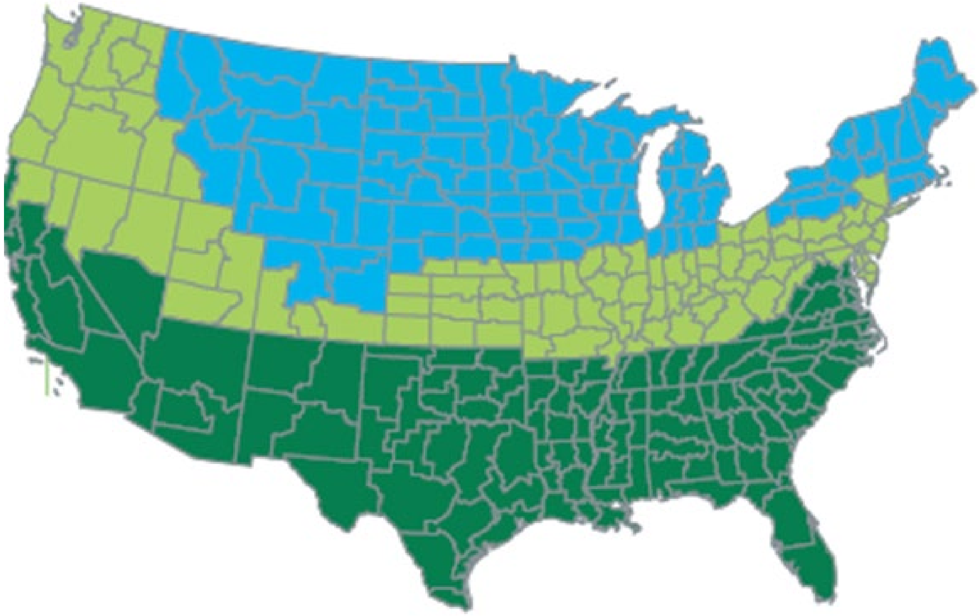


**Figure 2.3**: Switchgrass Growing Regions Based on Day Length (Blade Energy Crops, 2009)

Although both ecotypes have their ideal growing regions, there is a transition zone where either ecotype can be successfully grown. This transition region is depicted above as the light green shaded region which encompasses the middle of the United States. Switchgrass can be grown on a large variety of soil types, however it is more productive on a well-drained, finer textured soil with a pH range from 5 to 8. Lowland switchgrass grows better on a wetter denser soil, as opposed to upland which is more productive on drier soil that is finer in texture.

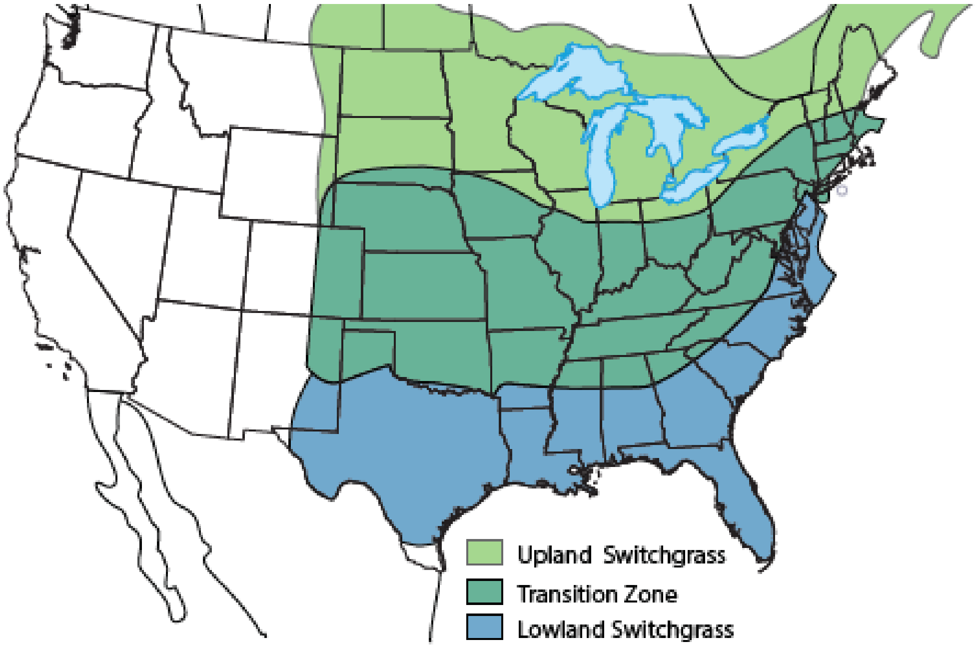


**Figure 2.4**: Map of Suitable Growing Regions for Each Switchgrass Ecotype (Casler et al, 2011)

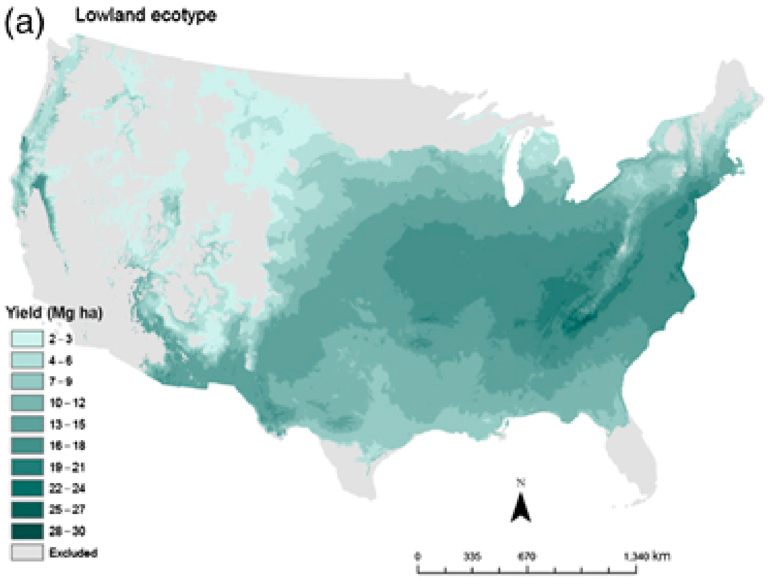
### Yield Potential

Assuming proper crop management methods are implemented, switchgrass for biomass can be very productive as a perennial crop. However, yields can vary widely as a function of precipitation and other environmental factors, which means that determining the most suitable variety for the specific region is crucial to maximizing yield potential.

Fike and colleagues, over a span of 10 years in the upper southeastern region of the United States, found that switchgrass managed for biomass production maintained yields at or around 14 Mg/Ha once stands reached maturity. They concluded that with more precise management combinations and site selection yields could be further enhanced. The greatest issues identified for further study were nitrogen (N) interactions with other nutrients, N use efficiency, and the rate of impact that N use has on long-term stand survival rates (Fike et al, 2006).

A seven year study, from 1994-2001, conducted at Oklahoma State University agricultural research stations in Chickasha and Haskell, OK identified that average biomass yields for Alamo and Kanlow varieties differed significantly in the two different locations. Both varieties were grown from 1994-2000 at each location, but the average annual precipitation varied from 44 inches at the Chickasha location to 33 inches at the Haskell location. Yields averaged 7.6 and 7.96 tons/acre/year in Chickasha and 2 tons/acre/year in Haskell. The almost ten inch difference in rainfall over the same period at the Haskell location resulted in significantly lower yields. Both Alamo and Kanlow are lowland types and typically produce higher yields than lowland ecotypes. Lowland types such as Blackwell and Caddo have been shown to thrive in dryer regions with lower average rainfalls. In the same study the lowland varieties yielded 5.7 and 5.6 tons/acre/year at the Haskell location.

The figure below represents the mapping analysis extrapolated from an empirical yield prediction model put together using numerous field studies from around the country. Jaeger et al (2010) estimated average yield for each switchgrass ecotype using a generalized logistic regression model then mapped out estimates of potential yields on land that is available for planting switchgrass. It shows the continually held assumptions that lowland yields are typically higher than upland yields, however upland yields were increased at higher altitudes compared to lowland. When compared to the map in figure 2.5, upland yield predictions are highest in the northeastern upland zone and lowland yields are increased throughout much of the transition zone and less substantial in the annotated lowland zone.



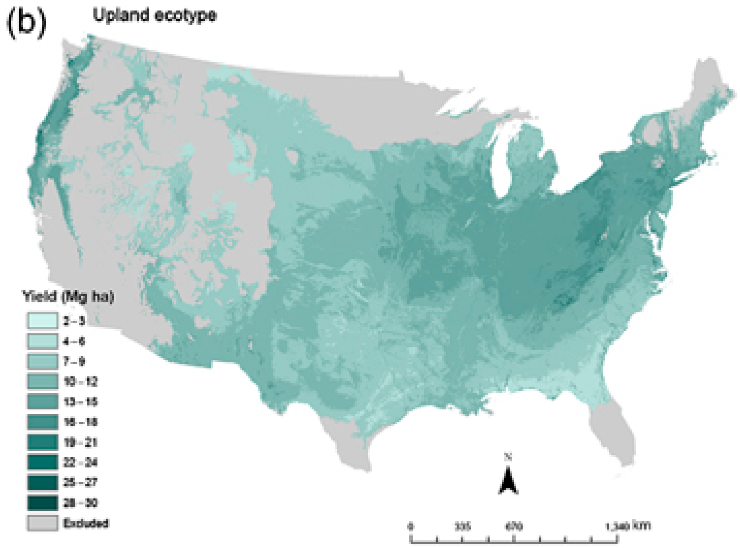


**Figure 2.5:** Maps of Predicted Switchgrass Yield for Lowland and Upland Varieties (Jaeger et al, 2010)

Assuming that yields can be somewhat consistent over the life of the stand, with a typical stand life span of ten years, switchgrass can be a very attractive alternative or supplemental option in operations throughout the United States. However, the real concern is the likelihood of having a successful first stand establishment and the amount of maintenance required to keep a stand productive throughout the expected lifetime.

## Stand Establishment

The seeding year is the most critical for potential producers, as having a successful stand establishment is the only way to have an economically feasible bioenergy production system (Perrin et al, 2008). Critical to a successful stand establishment is field preparation, nutrient management, and weed control. Research at the Samuel Roberts Noble Foundation has shown that extensive tillage and seedbed preparation can lead to higher rates of stand establishment and is better suited for switch grass seeding. Rogers and Nichols (2013) found that switchgrass planted into a tilled prepared seedbed led to a 62% first year stand establishment success rate as opposed to the 14% establishment rate of seeding into no-tilled terminated Bermuda grass residue. Stand establishment is best suited for previously retired crop fields, as opposed to typical perennial pastures which may require years to eliminate existing vegetation. Whether existing vegetation is eliminated with extensive tillage or the use of an approved broad-spectrum herbicide, fields should be completely clear of existing vegetation and have limited crop residue prior to seeding.  In fields without existing vegetation and minimal crop residue, site preparation can begin as early as six months in the fall prior to seeding. A soil test is typically done to determine potassium (K) and phosphorus (P) requirements to increase seedbed fertility at the time of planting. Establishment rates are optimum in seedbeds with a pH between 5 and 8. A pH of 6 is recommended for seedbeds prior to seeding, which can be achieved by incorporating lime in the fall to allow the pH to adjust before spring planting.  Nitrogen application in the establishment year is not recommended as it can lead to increased weed competition. Seedbeds should be plowed, disked, and packed to achieve a smooth firm packed soil. This generally requires the use of a roller packer or cultipacker. Generally seedbeds should be firm enough that a footprint is about one quarter inch deep (Blade, 2009).

Seeding with traditional grain drills is recommended at a rate of 5 to 6 lbs. of pure live seed (PLS) per acre at ¼ in to ½ in depth in finer soils and ¾ in in coarser soils (Blade, 2009). Seeding is typically done in the spring and switchgrass germination occurs when average soil temperature is at or near 60° F, which is usually between April 1st and May 1st.  Planting before early May allows for adequate root system development, which increases drought tolerance in the hotter summer months and reduces the negative effects of weed competition.  Seeding at different rates and row spacing intervals have resulted in similar yields. Germination typically occurs between 3 to 14 days.  Seedlings should be inspected 2-3 weeks after planting to determine adequate stand dispersion. A technique used to evaluate stand establishment is to take a 5ft by 5ft square with 1ft by 1ft sections and place it in 4 random areas in the field and count the number of squares that have seedlings present. A stand count at or greater than 50 percent or a plant per square foot is usually considered successful (Rogers and Nichols, 2013).

Weed management is crucial in the establishment year as competition is higher. Typical methods of weed control include mowing over the tops of the crop and using herbicides approved for switchgrass.  Mowing can be effective as long as it is done before the plant stems have elongated. Herbicides such as glyphosphate and paraquat can be used as a burn down application prior to emergence. Post emergence herbicides such as 2,4-D should not be applied until stands reach 3 to 4 in tall. Before applying herbicides producers should be sure that correct chemicals are selected and labels are followed so that new stands aren't damaged.

Although stands have been established successfully in the establishment year, switchgrass may not reach maturity until 2-3 years. This means that stands may only be 30-40 percent as productive in the establishment year. This reduction in yield can deter producers from harvesting in the establishment year to allow stands to mature.

## Crop Maintenance

Established switchgrass stands generally don't need much maintenance, however many field studies have shown a significant response to N application. N requirements for swithchgrass are a function of yield potential for the field, specific cultivar, and crop management practices being used (Vogel et al 2002). Therefore, specific application guidelines vary throughout the country based on region and climate. Yields have been optimized in the Great Plains and Midwest region by applying 20 lbs/acre of N for each ton of anticipated biomass. When harvest occurs after a killing frost 10 lbs/acre of N for each anticipated ton was optimal. General guidelines for nitrogen application state that anywhere from 0-75 lbs/acre is sufficient to combat nutrient removal and maintain soil quality. Although N application above 10 lbs/acre can increase weed competition, after the first year it is less likely to be a significant problem.

## Harvest

Due to the extensive practices of harvesting and maintaining hay bales for livestock forage, many farms are readily equipped, for the most part, to implement a switchgrass for bioenergy production strategy. With a few minor tweaks to already proven management methods, farmers can utilize the extensive knowledge base and local extension resources to effectively grow and harvest switchgrass for a bioenergy supply chain. Productive stands can be harvested and dried efficiently by implementing commercial haying equipment. This includes cutting switchgrass with self-propelled windrowers, generally at a 10-15 cm cutting height, in order to maximize the windrow's elevation above the soil and facilitate a faster drying process. This ensures that moisture content is less than 20% prior to baling. Windrows can be baled in large round bales or large rectangular bales. Large round bales typically minimize dry matter loss during storage, however rectangular bales tend to be easier to transport and handle. (Mitchell and Schumer, 2012)

Harvesting switchgrass once a year typically has been shown to maximize dry matter production and maintain stand health. Sanderson et al (2004) found that in Texas, Alamo switchgrass yields were optimized with a single autumn harvest, maintaining stands more effectively than harvesting twice in a single growing season. Yields ranged from 8-20 Mg ha-1 and soil organic carbon increased by 42 percent. Frank et al conducted a study in North Dakota on Sunburst and Dacotah cultivars with a single autumn harvest after applying 67 kg N/ ha-1, in which they observed biomass yields of 9.1 and 6.4 Mg ha-1. A Pennsylvania study observed the difference between harvesting switchgrass in autumn after a killing frost or postponing harvest until the spring. Leaving stands over the winter resulted in 20-24% yield reduction as opposed to the autumn harvest after a killing frost (Adler et al, 2006).

The removal of nutrients from the soil during harvest is a critical factor in maintaining stand longevity and continuity of sustainable biomass yields. The most critical to underlying production costs and biomass yields is N removal during harvest. For example, a typical harvest of 10 Mg/ha in the fall removes 100 kg of N per hectacre, but if harvest is delayed until after senescence resulting N removal is decreased by 40% (Mitchell and Schumer, 2012). Optimizing biomass yield has been shown to reduce N concentration by close to the same amount applied during the growing season. Delaying harvest, as stated before, does however result in a significant yield reduction and will have to be considered in selecting a harvest strategy. Managing N concentration is critical because it is the most expensive of all the nutrients to fertilize.

## Storage

The ability to supply biorefineries year round will depend on storage management of harvested biomass. Based on typical harvest methods that have been proven effective in optimizing biomass yield, biomass is stored in large round or rectangular bales. Key to effective storage is minimizing dry matter loss during storage, and it starts with in field drying of the windrows in order to safely bale the large quantities of biomass. Although conditioners on windrowers aid in drying by crushing plant stems without affecting plant composition, cut windrows need to dry prior to baling. This means selecting a harvest period when weather permits adequate in field drying time prior to baling and can influence harvest timing. For round bales moisture content should be below 18%, and below 16% for large rectangular bales. This ensures that bale composition is maintained and mitigates spontaneous combustion of the bales if moisture content is too high. (Mitchell and Schumer, 2012)

## Previous Switchgrass Production Budgets

A study of the farm scale production costs of switchgrass for biomass, for 10 commercial size farms over a span of five production years, from northern North Dakota to southern Nebraska reported an average cost of $65.86 per Mg of biomass dry matter, with an annualized average yield of 5 Mg/ha (Perrin et al, 2008). They broke down the cost of each field operation at each site into; seeding and planting, fertilizing, weed control, harvest, and land rent per hectare. In their cost analysis the two biggest cost factors were land rent at 45% and machinery and labor expenses, which were combined to reflect a single value custom rate, at 33% of the total annualized costs.

Epplin (1996) determined the cost of producing and delivering 1 dry Mg of switchgrass to a biomass conversion facility in the southern plains to be $37.08 Mg-1. The estimates were broken out to be; establishment at 14% of total cost, 22% for land rental costs, 32% for stand maintenance and harvest operations, and 32% for loading and transportation to the conversion facility. His estimated cost of establishing stands on a single hectare was $46.35, amortized at 9% over a 10 year life of the stand, with total operating costs dominating at 58% of the cost. Fixed machinery costs were estimated to be 16% of the total, and land rental cost to 25%. Machinery costs were taken from past models by Kletke and Sestak (1991) and Hunkhe and Bowers (1994).

Many more studies like the two above have been done to estimate the cost to produce and deliver switchgrass to a bio-refinery (Duffy 2007; Gerloff 2008, Grifith et al 2014). All use fixed machinery and operating costs from production budgets developed by university extension offices. Although these studies can give a good estimate on the feasibility of producing switchgrass for differing regions, they do not provide the specificity needed for potential individual producers to make non biased production decisions.

## Previous Models

Much research has been published on models developed for the optimization of a Biomass Supply Chain (BSC) and the study of Biomass Supply Chain Network Design (BSCND). According to Ghaderi, Pishvaee, and Moini (2016), who evaluated 146 papers on BSCND, concerning strategic decision making, published from January 1997 to July 2016, 92.5% of the reviewed papers used a mathematical programming approach, with 88.1% of those being linear and only 11.8% being non-linear models. Of those using a mathematical programming approach, Mixed Integer Linear Programming (MILP) was the most widely used, which allowed modelers to determine an appropriate BSCND as well as an optimal material flow between nodes simultaneously (Ghaderi, Pishvaee, and Moini). Ba, Prins, and Prodhon (2015), reviewing 124 papers relating to the optimization and performance evaluation of a BSC, concluded that mathematical programming models are able to optimize BSC's well with very detailed precision. This made them more suited for strategic and tactical level decision making, but they lacked the flexibility required to be applicable at the operational level. Whereas a simulation approach has enough flexibility to analyze multiple scenarios and would be more adept at analyzing operational and tactical level decisions, but lacked the optimization capability (Ba, Prins, and Prodhon, 2015).

Based on this, the simulation approach appears to be the best way to analyze different production parameters at the operational level, because of the flexibility required for an in-depth sensitivity analysis and process evaluation. However, this approach would require a complex design using advanced programming, making it difficult to replicate by anyone other than the model designer, which would limit the ability for individual producers to analyze their operations.

If a simulation approach is used for analyzing BSC's, the design would have to be fairly straight forward in the relationship between multiple processes, with specific parameters being robust enough to be adaptable in multiple scenarios. By doing so, models can be easily adjusted to individual resource constraints producers face, a BSC can be replicated to analyze scenarios over multiple time horizons, and users would have the ability to analyze a static environment for individual process optimization. Future research dedicated to analyzing BSC's should be robust and dynamic in the factor inputs, allowing the model to be flexible in evaluating multiple scenarios and resource constraints, while being strict enough in the design of relationships between individual processes to enhance scalability and allow multiple users to adapt the model to their individual constraints easily.

The originality of this research is based on the idea that the costs of producing switchgrass have already been estimated for specific production processes using generalized production strategies and factor input costs based on previous literature, but none of the existing literature has integrated models for each production aspect that can be specified to an individual operation. A decision tool that producers can use to model their individual operations, using their current and past production data as well as estimates from existing models for each factor input and associated costs, can aid in the overall production decision as well as identify areas that can enhance production efficiency.

# CHAPTER III

## CONCEPTUAL FRAMEWORK

The GLADIS tool estimates total production costs of growing switchgrass for biomass production. To do this GLADIS sums the dynamically-determined process costs and calculates total production cost. The switchgrass production processes are: field preparation, seeding, initial stand establishment, crop maintenance, harvest, storage, and biomass transport. A flowchart of GLADIS is shown in Figure 3.1.

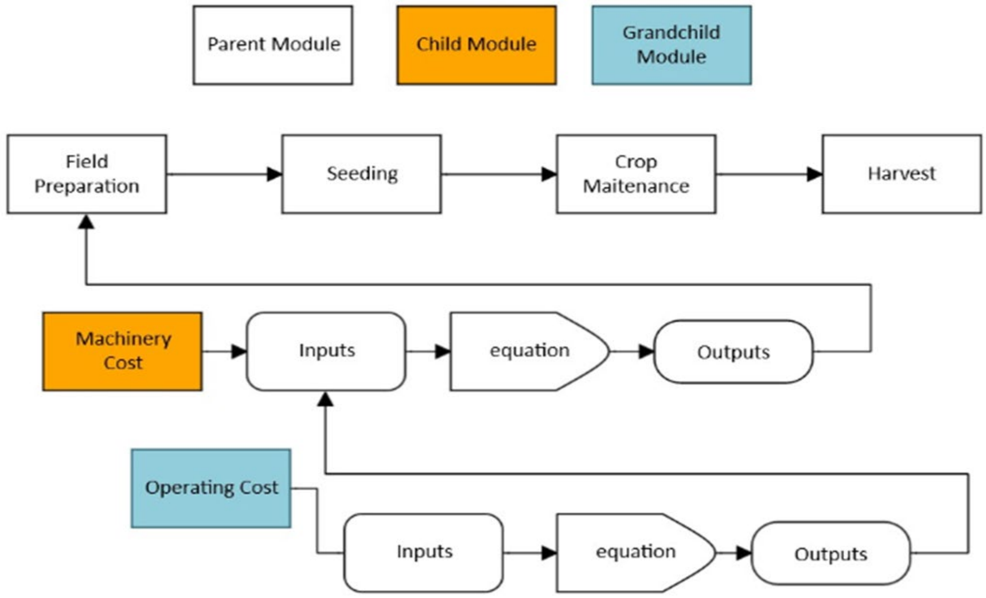


**Figure 3.1**: Biomass Supply Chain (BSC) Schematic for Switchgrass Production

To estimate the costs associated with each of these processes, the inputs and outputs, along with their respective equations, are specified in modules. The system simulates costs using a step based procedure. The simulation calculates the costs specified in children or grandchildren modules and then maps those costs to their respective parent modules. In this case a parent module would be one of the processes specified in Figure 3.1.

For example, a child module of field preparation costs would be the total machinery costs for preparing the land and a grandchild module would be machinery operating cost. The relationships between children and parent modules must be specified correctly, because the system is coded so that a child module's output can only be mapped to their parent module. This means that the model has to be flexible in modules not inputs for the simulation to run correctly. More specifically, the child and grandchild module's respective inputs should be interchangeable or easily manipulated, as this allows the simulation to calculate the more variable or sensitive inputs first before calculating the outputs that map as inputs to parent modules. For the example above, this means that the tool has to calculate the costs associated with machinery operating cost first. Then it would map those cost outputs to the inputs specified in the overall machinery cost module and generate the total machinery cost for that process, mapping those outputs to the parent module inputs, which would finally contribute to calculating the cost of field preparation.

Once the parent module is created with the appropriate child and grandchild modules it can be cloned and used in other parent modules. If the mapping is correct for the machinery costs it can be cloned and replicated in all the other processes all that would need to be changed is the specific inputs to match the machinery for each production process. This allows for rapid expansion of the simulation by just replicating already established parent modules and only having to modify the specific inputs for those modules. A more detailed mapping of a generic machinery cost simulation is shown in figure 3.2.

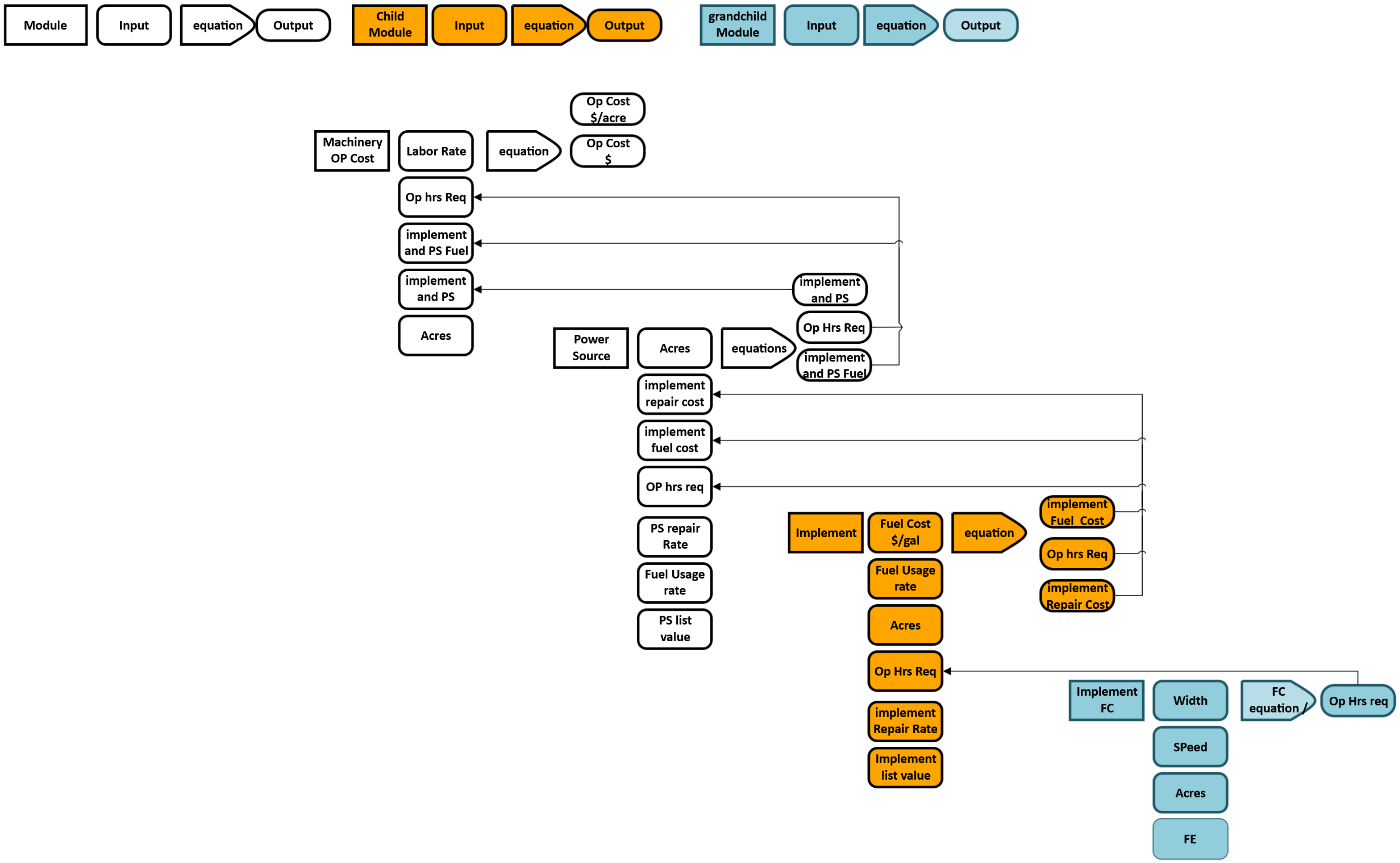


**Figure 3.2**: Farm Machinery Cost Simulation Mapping Schematic

The system is intended to aid producers by being as user friendly as possible. Right now only administrators can build modules in GLADIS. This means users will not have to create modules from scratch or map the parent and child module relationships. Users will only have to input the values for each module based on the resource constraints they face. Once all of the inputs for each module are put in, the simulation is run to arrive at the individual producer's cost function, which is based on the values that producer inputs into each module.

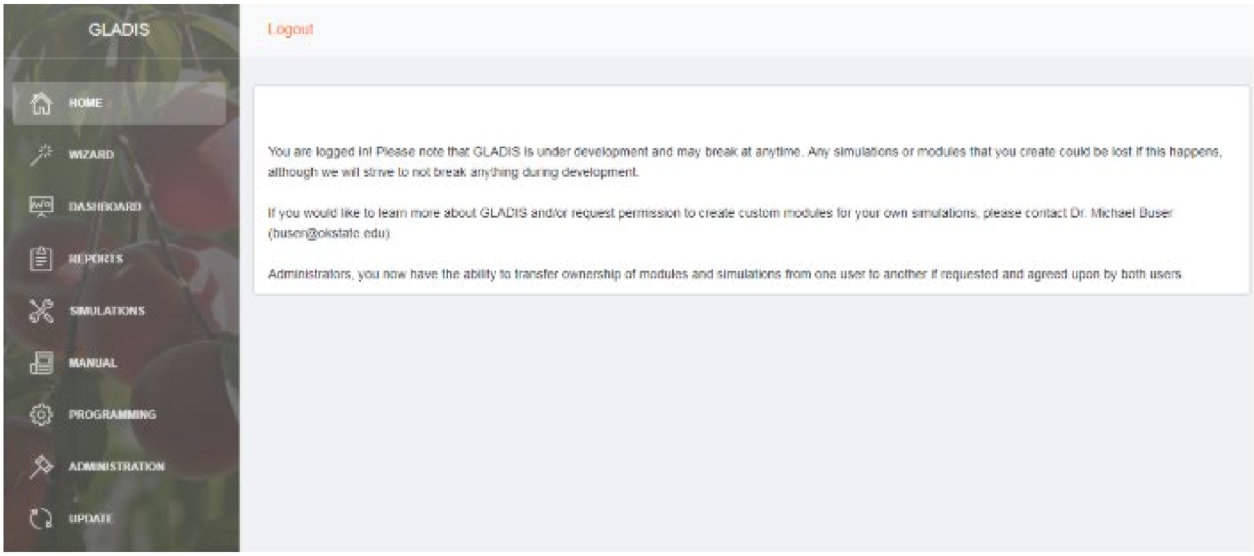
To estimate production costs of a switchgrass driven BSC in GLADIS, analysis of different production practices and the decision variables associated with those practices is required. The general model consists of various parent modules created to reflect individual processes, which are then be used to map the specific relationships for each production process. A general simulation is mathematically represented as

$$Cost = \sum_{i=1}^{n} C(BSC_i) = C(Fp_i) + C(Se_i) + C(Cm_i) + C(Hrv_i) \tag{3.1}$$

where: $i$ is the number of iterations, $C(BSC_i)$ is the total switchgrass production cost faced by an individual producer, $C(Fp_i)$ is the cost of the field preparation process cost, $C(Sd_i)$ is the cost of seeding, $C(Cm_i)$ is the cost of maintaining the crop, and $C(Hrv_i)$ is the cost of harvesting. Each of these process modules are mapped as parent modules in the overall simulation, but their children and grandchildren modules house the cost estimation models and their respective inputs identified from the existing literature. This satisfies the condition of only being able to map the outputs of children modules to the parent modules inputs.

## GLADIS Interface

To use GLADIS, the user has to create an account, which then has to be approved by an administrator. After the account is created the user can log in and start creating simulations. The home page is shown in figure 3.3 below.



You are logged in! Please note that GLADIS is under development and may break at anytime. Any simulations or modules that you create could be lost if this happens, although we will strive to not break anything during development.

If you would like to learn more about GLADIS and/or request permission to create custom modules for your own simulations, please contact Dr. Michael Buser (buser@okstate.edu)

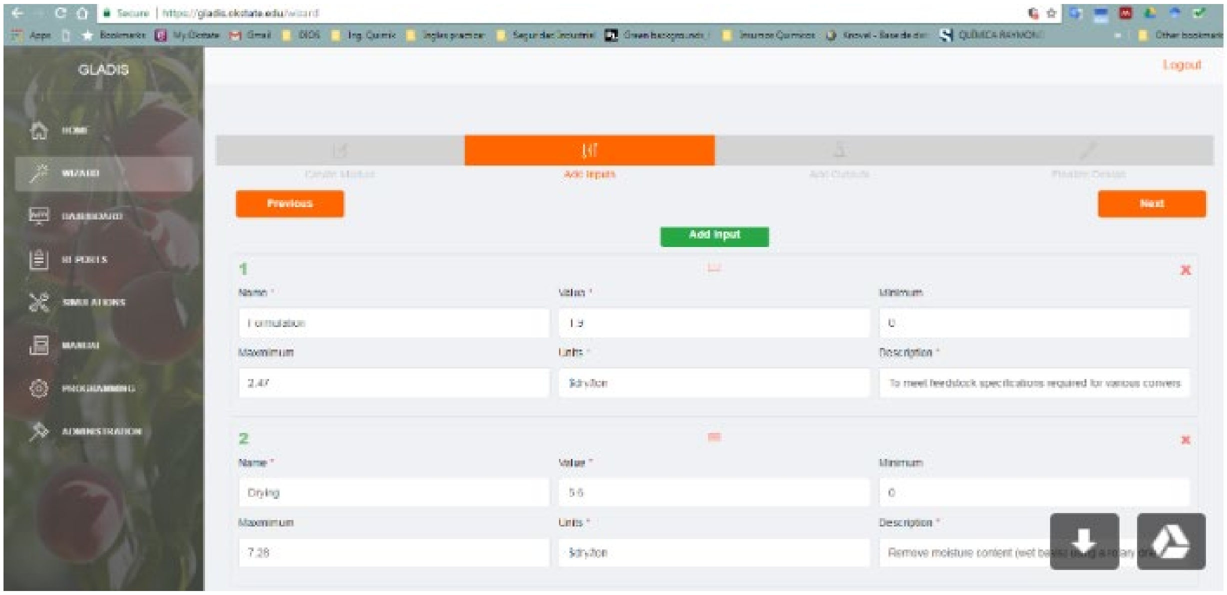
Administrators, you now have the ability to transfer ownership of modules and simulations from one user to another if requested and agreed upon by both users

**Figure 3.3:** GLADIS Homepage for Administrators Screenshot

Right now GLADIS users are placed into two categories; administrators and users. Users cannot access the Module Builder Wizard or Administration functions, however they will still be able to build their own simulations utilizing modules built by the admins and access the reports generated. Before beginning a simulation users can access the GLADIS manual to learn how to properly map modules and build simulations. Because the interface is meant to be as user friendly as possible, the default simulation should be in depth enough to get started with mapping BSC's. Users will only have to match specific inputs to their resource constraints.

## Module Building in the Wizard Tool

Modules are built by administrators and then mapped in the overall default simulation. The Wizard tool allows admins to create modules from scratch, specifying inputs and the equations necessary to generate the needed outputs for calculating costs. A screenshot of the wizard is shown in figure 3.4.



1

Name *: Formulation
Value *: 1.9
Minimum: 0
Maximum: 2.47
Units *: $dry/ton
Description *: To meet feedstock specifications required for various convers

2

Name *: Drying
Value *: 5.6
Minimum: 0
Maximum: 7.28
Units *: $dry/ton
Description *: Remove moisture content (wet basis) using a rotary dr

**Figure 3.4:** GLADIS Wizard Interface Screenshot

In the wizard, the module is first named and given a brief description and given a tag. The tag designated will group modules with the same tag together, so those modules can be accessed quickly in the simulation builder allowing for increased organization. Then the inputs are specified with names, descriptions, units, values, maximums, and minimums in the "Add Inputs" tab. So for example, a created module would be Fuel Cost. The description would be, "Farm Diesel Fuel Cost", and it would only have 1 input being fuel cost, with a value or range of values specified by a single amount or maximum and minimum taken from current data. Units would be, "$/gal". After the inputs are created, outputs are named and described in the "Add Outputs" tab. For the example, the output would be “$/gal”. The next step would be to finalize the outputs in the “Finalize Outputs” tab. Here equations are built to generate the required outputs for the module. Equations are modified in the edit tool of the wizard, shown in figure 3.5.

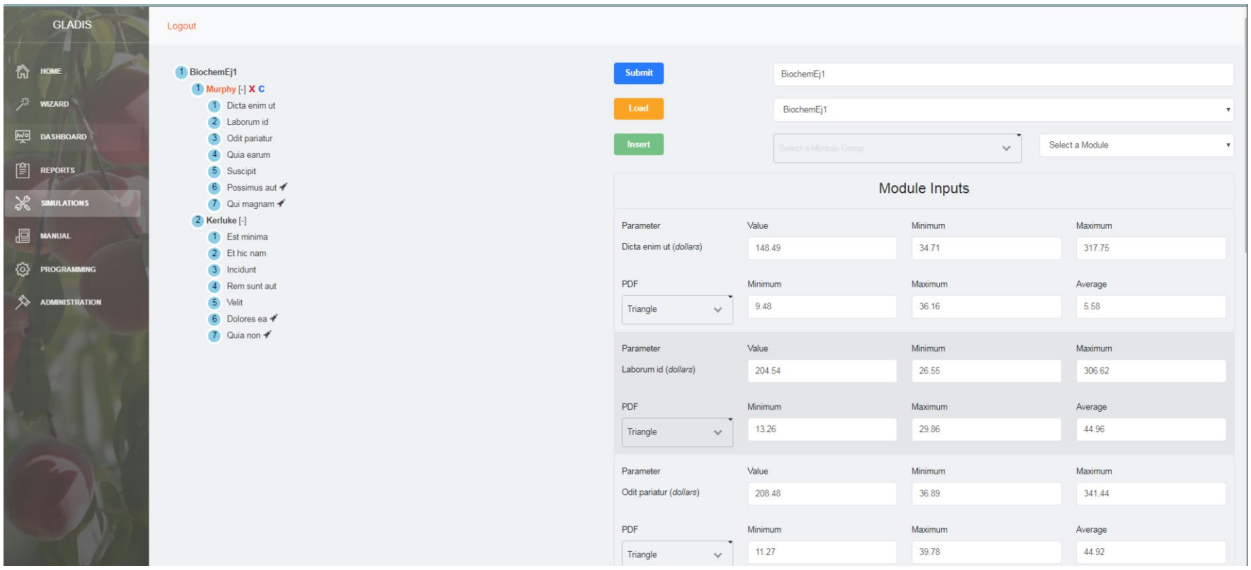
```
test = {

    //Inputs
    formulation_units: '$dry/ton',
    formulation: 1.90,

    drying_units: '$dry/ton',
    drying: 5.60,

    grinderb_units: '$dry/ton',
    grinderb: 2.40,

    separation_units: '$dry/ton',
    separation: 5.00,

    grindera_units: '$dry/ton',
    grindera: 5.10,

    //Outputs
    preprocost_units: '$ / dry ton',
    get preprocost() {
        return 0;
    },

}
```

**Figure 3.5:** GLADIS Wizard Editor Tool and Evaluate Function Screenshot

For the Fuel Cost module specified above, the equation would just be Fuel Cost multiplied by 1, which would return the Fuel Cost in $/gal as an output. The tool also has an evaluate function which will evaluate all the specified equations for each output and test the functionality before finalizing the module. Once the module is finalized it can be mapped as a child module into the necessary parent module. The example, “Fuel Cost” would be mapped as an input into another module such as Implement Operating Cost to calculate the Fuel Cost for a specific implement used in a production process.

## Simulation Building

After all the necessary modules are created, the entire simulation can be built by mapping the respective parent, child, and grandchild modules. The user does this in the "Simulations" Tab shown in figure 6. The simulation is built using an interactive tree builder. In the example below, the tree has the overall simulation, the child module with the respective outputs, and then the grandchild module with the respective outputs, of which the last two are mapped back to the child module.



1 BiochemEj1
  1 Murphy [-] X C
    1 Dicta enim ut
    2 Laborum id
    3 Odit pariatur
    4 Quia earum
    5 Suscipit
    6 Possimus aut
    7 Qui magnam
  2 Kerluke [-]
    1 Est minima
    2 Et hic nam
    3 Incidunt
    4 Rem sunt aut
    5 Velit
    6 Dolores ea
    7 Quia non

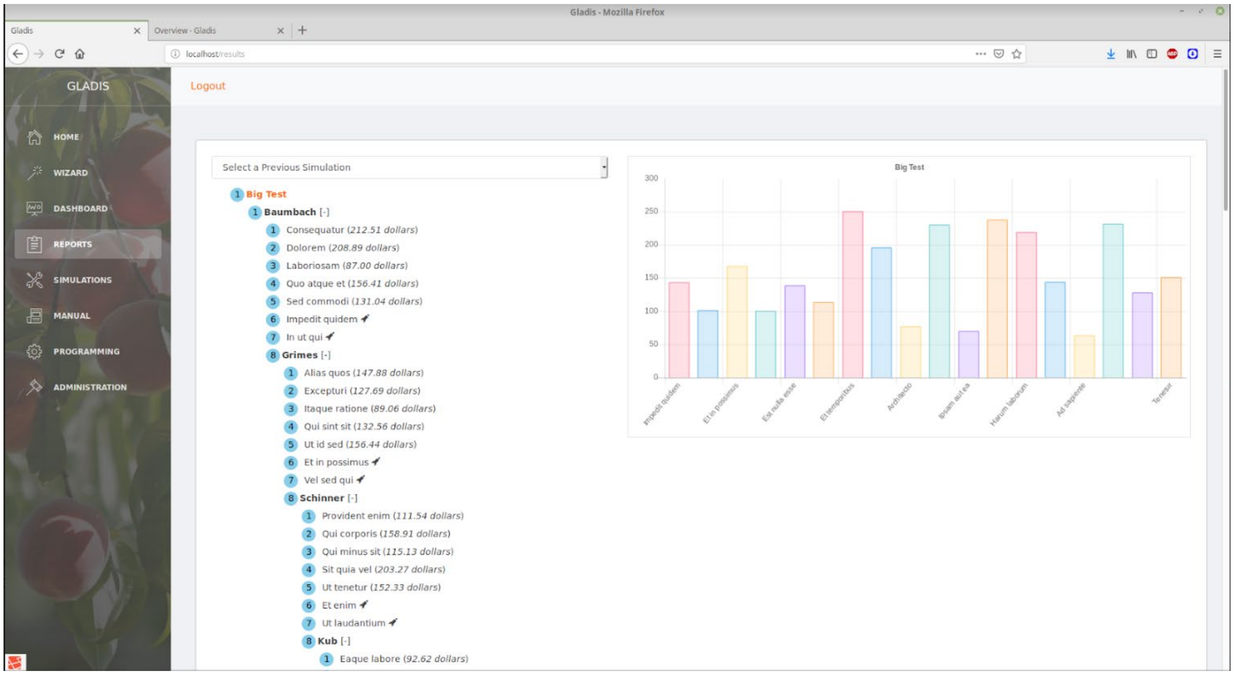
BiochemEj1

BiochemEj1

| Parameter | Value | Minimum | Maximum |
|---|---|---|---|
| Dicta enim ut (*dollars*) | 148.49 | 34.71 | 317.75 |
| **PDF** | **Minimum** | **Maximum** | **Average** |
| Triangle | 9.48 | 36.16 | 5.58 |
| **Parameter** | **Value** | **Minimum** | **Maximum** |
| Laborum id (*dollars*) | 204.54 | 26.55 | 306.62 |
| **PDF** | **Minimum** | **Maximum** | **Average** |
| Triangle | 13.26 | 29.86 | 44.96 |
| **Parameter** | **Value** | **Minimum** | **Maximum** |
| Odit pariatur (*dollars*) | 208.48 | 36.89 | 341.44 |
| **PDF** | **Minimum** | **Maximum** | **Average** |
| Triangle | 11.27 | 39.78 | 44.92 |

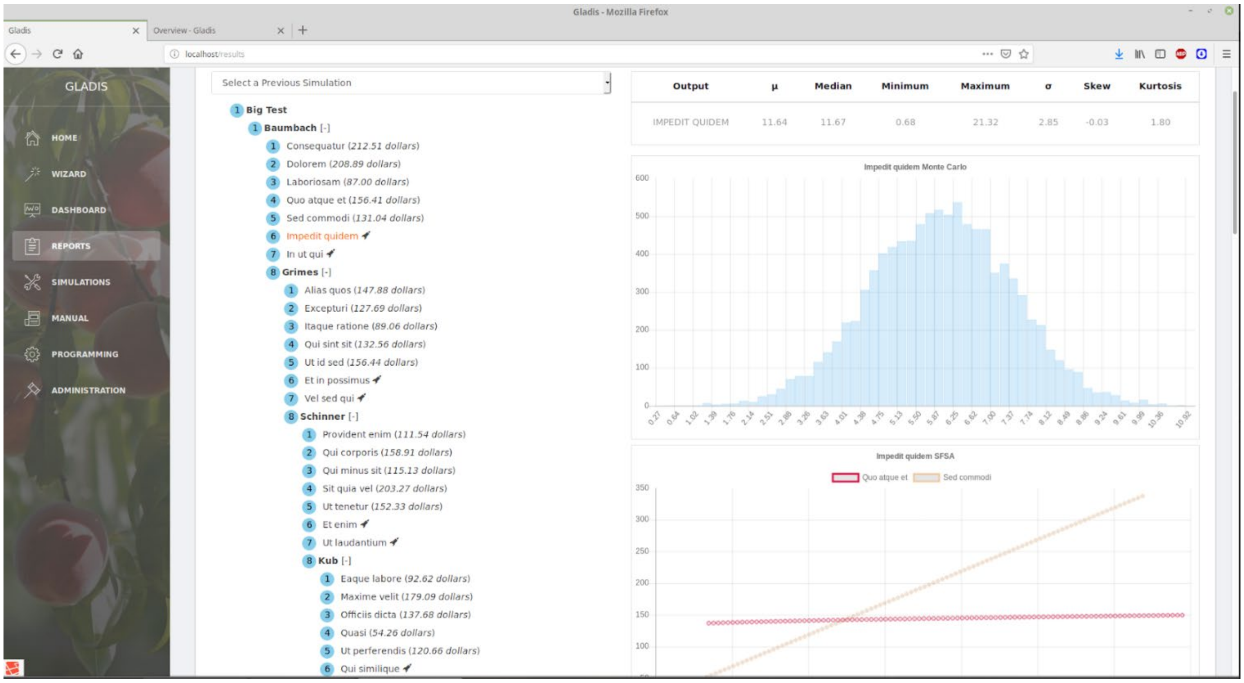
**Figure 3.6:** GLADIS Simulation Builder Screenshot

Once in the simulation builder, the user names the simulation and maps the modules to build a simulation. Building a simulation is easy because Pre-built modules can be selected and added to the new simulation and each input value is entered by the user. Probability density functions can be selected from this page. After all the Inputs are specified, the simulation is run and the calculated output can be viewed from the Repots tab, shown in figure 7.



- ① **Big Test**
  - ① **Baumbach** [-]
    - ① Consequatur (*212.51 dollars*)
    - ② Dolorem (*208.89 dollars*)
    - ③ Laboriosam (*87.00 dollars*)
    - ④ Quo atque et (*156.41 dollars*)
    - ⑤ Sed commodi (*131.04 dollars*)
    - ⑥ Impedit quidem 🚀
    - ⑦ In ut qui 🚀
    - ⑧ **Grimes** [-]
      - ① Alias quos (*147.88 dollars*)
      - ② Excepturi (*127.69 dollars*)
      - ③ Itaque ratione (*89.06 dollars*)
      - ④ Qui sint sit (*132.56 dollars*)
      - ⑤ Ut id sed (*156.44 dollars*)
      - ⑥ Et in possimus 🚀
      - ⑦ Vel sed qui 🚀
      - ⑧ **Schinner** [-]
        - ① Provident enim (*111.54 dollars*)
        - ② Qui corporis (*158.91 dollars*)
        - ③ Qui minus sit (*115.13 dollars*)
        - ④ Sit quia vel (*203.27 dollars*)
        - ⑤ Ut tenetur (*152.33 dollars*)
        - ⑥ Et enim 🚀
        - ⑦ Ut laudantium 🚀
        - ⑧ **Kub** [-]
          - ① Eaque labore (*92.62 dollars*)

**Figure 3.7:** GLADIS Reports Viewer Screenshots



| Output | µ | Median | Minimum | Maximum | σ | Skew | Kurtosis |
|---|---|---|---|---|---|---|---|
| IMPEDIT QUIDEM | 11.64 | 11.67 | 0.68 | 21.32 | 2.85 | -0.03 | 1.80 |

- ① **Big Test**
  - ① **Baumbach** [-]
    - ① Consequatur (*212.51 dollars*)
    - ② Dolorem (*208.89 dollars*)
    - ③ Laboriosam (*87.00 dollars*)
    - ④ Quo atque et (*156.41 dollars*)
    - ⑤ Sed commodi (*131.04 dollars*)
    - ⑥ Impedit quidem 🚀
    - ⑦ In ut qui 🚀
    - ⑧ **Grimes** [-]
      - ① Alias quos (*147.88 dollars*)
      - ② Excepturi (*127.69 dollars*)
      - ③ Itaque ratione (*89.06 dollars*)
      - ④ Qui sint sit (*132.56 dollars*)
      - ⑤ Ut id sed (*156.44 dollars*)
      - ⑥ Et in possimus 🚀
      - ⑦ Vel sed qui 🚀
      - ⑧ **Schinner** [-]
        - ① Provident enim (*111.54 dollars*)
        - ② Qui corporis (*158.91 dollars*)
        - ③ Qui minus sit (*115.13 dollars*)
        - ④ Sit quia vel (*203.27 dollars*)
        - ⑤ Ut tenetur (*152.33 dollars*)
        - ⑥ Et enim 🚀
        - ⑦ Ut laudantium 🚀
        - ⑧ **Kub** [-]
          - ① Eaque labore (*92.62 dollars*)
          - ② Maxime velit (*179.09 dollars*)
          - ③ Officiis dicta (*137.68 dollars*)
          - ④ Quasi (*54.26 dollars*)
          - ⑤ Ut perferendis (*120.66 dollars*)
          - ⑥ Qui similique 🚀

**Figure 3.7 (continued):** GLADIS Reports Viewer Screenshots

The user can view the results and the different output distributions in different tables and charts that are built into GLADIS. The first screenshot in figure 7 shows the specific distribution of values for the calculated outputs for a specific module allowing the user to identify possible sensitivities for a specific modules outputs. The second screenshot shows a general chart of all the modules calculated output values, which allows the user to determine where the majority of costs are coming from.

# CHAPTER IV

## COST MAPPING AND RESULTS

The basic production scenario can be described by using the BSC schematic in figure 4.1. Production is classified into different production processes: field preparation, seeding, crop maintenance, first harvest, and all other harvests. This specific scenario will only look at the machinery costs associated with field preparation for stand establishment on cropland that was harvested in the fall using conventional tillage methods. This specific scenario is adapted from the production budgets Griffith et al, (2014) created. A list of the specific scenario activities is shown below in table 4.1.

**Table 4.1:** Stand Establishment on Cropland Harvested in the Fall Using Conventional Tillage Methods

| **Time Frame** | **Process Activity** |
|---|---|
| September-October | Test Soil |
| | Chisel Plow |
| | Fertilize |
| | Disk |
| April | Disk |
| | Cultipack |

Machinery costs account for the majority of production costs and therefore need to be estimated with great accuracy. The costs can be split into two categories; Machinery Ownership Costs and Machinery Operating Costs (Edwards, 2011).

## Estimating Farm Machinery Ownership Costs

Ownership costs are the fixed costs that result from owning the machinery year after year and putting a number of operating hours on that piece of machinery. They are comprised of depreciation, interest, taxes, insurance, and housing costs. The total cost of ownership for a machine annually would be the sum of the joint costs of depreciation, interest, the joint cost of property taxes, insurance, and housing.

Depreciation is the total value lost each year as a result of the wear and tear from age and use. It can be represented as the difference between the purchase price and the salvage value of that piece of the equipment. Salvage value is the estimated value that machinery has after a certain period of use. The salvage value, or percent of purchase price remaining, can be estimated using the American Society of Agricultural and Biological Engineers (ASABE) Remaining Salvage Value Tables shown in table 4.2 and 4.3. Table 4.2 gives the percentage of the purchase price remaining for a tractor based on the horsepower of the tractor, age, and the annual operating hours. Table 4.3 shows the percentage of the list price an implement still has based on the type of implement used and the machine age.

**Table 4.2:** ASABE Remaining Salvage Value Table for Tractors (ASABE, 2011)

| Tractor Type | Annual Machine Hours | Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30-79 HP Tractor | 200 |  | 65% | 59% | 54% | 51% | 48% | 45% | 42% | 40% | 38% | 36% | 35% | 33% | 32% | 30% | 29% | 28% | 26% | 25% | 24% | 23% |
| 30-79 HP Tractor | 400 |  | 60% | 54% | 49% | 46% | 43% | 40% | 38% | 36% | 34% | 32% | 31% | 29% | 28% | 27% | 25% | 24% | 23% | 22% | 21% | 20% |
| 30-79 HP Tractor | 600 |  | 56% | 50% | 46% | 43% | 40% | 37% | 35% | 33% | 31% | 30% | 28% | 27% | 25% | 24% | 23% | 22% | 21% | 20% | 19% | 18% |
| 80-149 HP Tractor | 200 |  | 69% | 62% | 57% | 53% | 50% | 47% | 44% | 42% | 40% | 38% | 36% | 34% | 33% | 31% | 30% | 28% | 27% | 26% | 25% | 24% |
| 80-149 HP Tractor | 400 |  | 68% | 62% | 57% | 53% | 49% | 46% | 44% | 41% | 39% | 37% | 35% | 34% | 32% | 31% | 29% | 28% | 27% | 25% | 24% | 23% |
| 80-149 HP Tractor | 600 |  | 68% | 61% | 56% | 52% | 49% | 46% | 43% | 41% | 39% | 37% | 35% | 33% | 32% | 30% | 29% | 27% | 26% | 25% | 24% | 23% |
| 150+ HP Tractor | 200 |  | 69% | 61% | 55% | 51% | 47% | 43% | 40% | 38% | 35% | 33% | 31% | 29% | 27% | 25% | 24% | 22% | 21% | 20% | 19% | 17% |
| 150+ HP Tractor | 400 |  | 67% | 59% | 54% | 49% | 45% | 42% | 39% | 36% | 34% | 32% | 30% | 28% | 26% | 24% | 23% | 21% | 20% | 19% | 18% | 17% |
| 150+ HP Tractor | 600 |  | 66% | 58% | 52% | 48% | 44% | 41% | 38% | 35% | 33% | 31% | 29% | 27% | 25% | 24% | 22% | 21% | 19% | 18% | 17% | 16% |
| Combine/Forage Harvester | 100 |  | 79% | 67% | 59% | 52% | 47% | 42% | 38% | 35% | 31% | 28% | 26% | 23% | 21% | 19% | 17% | 16% | 14% | 13% | 11% | 10% |
| Combine/Forage Harvester | 300 |  | 69% | 58% | 50% | 44% | 39% | 35% | 31% | 28% | 25% | 23% | 20% | 18% | 16% | 14% | 13% | 11% | 10% | 9% | 8% | 7% |
| Combine/Forage Harvester | 500 |  | 63% | 52% | 45% | 39% | 34% | 30% | 27% | 24% | 21% | 19% | 17% | 15% | 13% | 12% | 10% | 9% | 8% | 7% | 6% | 5% |

**Table 4.3:** ASABE Remaining Salvage Value Table for Implements (ASABE, 2011)

| Machine Type | Age | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Plows |  | 47% | 44% | 42% | 40% | 39% | 38% | 36% | 35% | 34% | 33% | 32% | 32% | 31% | 30% | 29% | 29% | 28% | 27% | 27% | 26% |
| Other Tillage |  | 61% | 54% | 49% | 45% | 42% | 39% | 36% | 34% | 31% | 30% | 28% | 26% | 24% | 23% | 22% | 20% | 19% | 18% | 17% | 16% |
| Planter, Drill, Sprayer |  | 65% | 60% | 56% | 53% | 50% | 48% | 46% | 44% | 42% | 40% | 39% | 38% | 36% | 35% | 34% | 33% | 32% | 30% | 29% | 29% |
| Mower, Chopper |  | 47% | 44% | 41% | 39% | 37% | 35% | 33% | 32% | 31% | 30% | 28% | 27% | 26% | 26% | 25% | 24% | 23% | 22% | 22% | 21% |
| Baler |  | 56% | 50% | 46% | 42% | 39% | 37% | 34% | 32% | 30% | 28% | 27% | 25% | 24% | 22% | 21% | 20% | 19% | 18% | 17% | 16% |
| Swather, Rake |  | 49% | 44% | 40% | 37% | 35% | 32% | 30% | 28% | 27% | 25% | 24% | 23% | 21% | 20% | 19% | 18% | 17% | 16% | 16% | 15% |
| Vehicle |  | 42% | 39% | 36% | 34% | 33% | 31% | 30% | 29% | 27% | 26% | 25% | 24% | 24% | 23% | 22% | 21% | 20% | 20% | 19% | 19% |
| Other |  | 69% | 62% | 56% | 52% | 48% | 45% | 42% | 40% | 37% | 35% | 33% | 31% | 29% | 28% | 26% | 25% | 24% | 22% | 21% | 20% |

Interest costs are the costs associated with borrowing dollars to purchase machinery, which are determined by the lending agency. If machinery is purchased using personal capital the interest cost associated would be the forgone benefit of investing that capital in other profitable operations. In order to estimate a "real interest rate" or inflation adjusted interest rate, which accounts for the decreased cost of paying back loans, an estimated inflation rate should be subtracted from the determined interest rate.

The total cost of depreciation and interest, or capital recovery, can be estimated by adding the total depreciation multiplied by the capital recovery factor to the salvage value multiplied by the real interest rate. The capital recovery factor for a piece of machinery can be estimated using table 4.4, which yields the recovery factor based on the real interest rate and the age of the machine.

**Table 4.4:** Capital Recovery Factors (Total Cost of Depreciation and Interest) Table, adapted from (Edwards, 2011)

| Age of Machine | Real Interest Rate | 2% | 3% | 4% | 5% | 6% | 7% | 8% | 9% | 10% | 11% | 12% | 13% |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 1.02 | 1.03 | 1.04 | 1.05 | 1.06 | 1.07 | 1.08 | 1.09 | 1.1 | 1.11 | 1.12 | 1.13 |
| 2 | | 0.515 | 0.523 | 0.53 | 0.538 | 0.545 | 0.553 | 0.561 | 0.568 | 0.576 | 0.584 | 0.592 | 0.599 |
| 3 | | 0.347 | 0.354 | 0.36 | 0.367 | 0.374 | 0.381 | 0.388 | 0.395 | 0.402 | 0.409 | 0.416 | 0.424 |
| 4 | | 0.263 | 0.269 | 0.275 | 0.282 | 0.289 | 0.295 | 0.302 | 0.309 | 0.315 | 0.322 | 0.329 | 0.336 |
| 5 | | 0.212 | 0.218 | 0.225 | 0.231 | 0.237 | 0.244 | 0.25 | 0.257 | 0.264 | 0.271 | 0.277 | 0.284 |
| 6 | | 0.179 | 0.185 | 0.191 | 0.197 | 0.203 | 0.21 | 0.216 | 0.223 | 0.23 | 0.236 | 0.243 | 0.25 |
| 7 | | 0.155 | 0.161 | 0.167 | 0.173 | 0.179 | 0.186 | 0.192 | 0.199 | 0.205 | 0.212 | 0.219 | 0.226 |
| 8 | | 0.137 | 0.142 | 0.149 | 0.155 | 0.161 | 0.167 | 0.174 | 0.181 | 0.187 | 0.194 | 0.201 | 0.208 |
| 9 | | 0.123 | 0.128 | 0.134 | 0.141 | 0.147 | 0.153 | 0.16 | 0.167 | 0.174 | 0.181 | 0.188 | 0.195 |
| 10 | | 0.111 | 0.117 | 0.123 | 0.13 | 0.136 | 0.142 | 0.149 | 0.156 | 0.163 | 0.17 | 0.177 | 0.184 |
| 11 | | 0.102 | 0.108 | 0.114 | 0.12 | 0.127 | 0.133 | 0.14 | 0.147 | 0.154 | 0.161 | 0.168 | 0.176 |
| 12 | | 0.095 | 0.1 | 0.107 | 0.113 | 0.119 | 0.126 | 0.133 | 0.14 | 0.147 | 0.154 | 0.161 | 0.169 |
| 13 | | 0.088 | 0.094 | 0.1 | 0.106 | 0.113 | 0.12 | 0.127 | 0.134 | 0.141 | 0.148 | 0.156 | 0.163 |
| 14 | | 0.083 | 0.089 | 0.095 | 0.101 | 0.108 | 0.114 | 0.121 | 0.128 | 0.136 | 0.143 | 0.151 | 0.159 |
| 15 | | 0.078 | 0.084 | 0.09 | 0.096 | 0.103 | 0.11 | 0.117 | 0.124 | 0.131 | 0.139 | 0.147 | 0.155 |
| 16 | | 0.074 | 0.08 | 0.086 | 0.092 | 0.099 | 0.106 | 0.113 | 0.12 | 0.128 | 0.136 | 0.143 | 0.151 |
| 17 | | 0.07 | 0.076 | 0.082 | 0.089 | 0.095 | 0.102 | 0.11 | 0.117 | 0.125 | 0.132 | 0.14 | 0.149 |
| 18 | | 0.067 | 0.073 | 0.079 | 0.086 | 0.092 | 0.099 | 0.107 | 0.114 | 0.122 | 0.13 | 0.138 | 0.146 |
| 19 | | 0.064 | 0.07 | 0.076 | 0.083 | 0.09 | 0.097 | 0.104 | 0.112 | 0.12 | 0.128 | 0.136 | 0.144 |
| 20 | | 0.061 | 0.067 | 0.074 | 0.08 | 0.087 | 0.094 | 0.102 | 0.11 | 0.117 | 0.126 | 0.134 | 0.142 |

Property taxes, insurance on machinery, and housing costs can be estimated separately or together in calculating the total ownership costs. The joint cost of taxes insurance and housing is 1 percent of the average value of the machinery if the property tax on machinery isn’t significant Edwards (2011). So the joint cost would be 1 percent of the sum of the purchase price and salvage value divided by 2. If property taxes are significant, a 2 percent of the average value could be assumed to account for the extra incurred costs.

## Estimating Farm Machinery Operating Costs

Machinery operating costs are the costs associated with using machinery to accomplish a specific task. These costs include labor, fuel, lubrication, and maintenance costs. Labor can be the hourly rate for a machine operator or it can be the expected wage rate of the producer. Labor hours typically exceed the operating hours required for completing a field process because of the added time of actually getting to the field and conducting maintenance on machinery. Edwards suggests that actual labor hours exceed field time by 10 to 20 percent. Therefore the hourly rate should be multiplied by a factor of 1.1 or 1.2. Fuel costs are calculated by multiplying the fuel usage rate per acre by the number of acres and then by the estimated cost of fuel. Properly lubricating farm machinery is crucial to achieving optimal in field performance. Lubrication costs are calculated by multiplying the total fuel cost by 15%, which was estimated from farm survey data Edwards (2011). Repair and maintenance costs can account for a significant portion of operating costs. Accurate estimation based on detailed record keeping is the best option for calculating repair costs, however a baseline can be established using the accumulated repair cost estimates from the values in tables 4.5 and 4.6. The accumulated repair cost can be estimated as the percent of list value using the type of machine and the accumulated machine hours.

**Table 4.5:** ASABE Repair Costs Estimates Table for Implements (ASABE, 2011)

| Type Of Machinery | Accumulated Hours | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 | 1200 | 1400 | 1500 | 1600 | 1800 | 2000 | 2100 | 2400 | 2700 | 3000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Moldboard plow | | | 2% | | 6% | | 12% | | 19% | | 29% | 40% | 53% | | 68% | 84% | 101% | | | | |
| Heavy-duty disk | | | 1% | | 4% | | 8% | | 12% | | 18% | 25% | 32% | | 40% | 49% | 58% | | | | |
| Tandem disk | | | 1% | | 4% | | 8% | | 12% | | 18% | 25% | 32% | | 40% | 49% | 58% | | | | |
| Chisel plow | | | 3% | | 8% | | 14% | | 20% | | 28% | 36% | 45% | | 54% | 64% | 74% | | | | |
| Field cultivator | | | 3% | | 7% | | 13% | | 20% | | 27% | 35% | 43% | | 52% | 61% | 71% | | | | |
| Harrow | | | 3% | | 7% | | 13% | | 20% | | 27% | 35% | 43% | | 52% | 61% | 71% | | | | |
| Roller-packer, mulcher | | | 2% | | 5% | | 8% | | 12% | | 16% | 20% | 25% | | 29% | 34% | 39% | | | | |
| Rotary hoe | | | 2% | | 6% | | 11% | | 17% | | 23% | 30% | 37% | | 44% | 52% | 61% | | | | |
| Row crop cultivator | | | 0% | | 2% | | 6% | | 10% | | 17% | 25% | 36% | | 48% | 62% | 78% | | | | |
| Combine heads | | | 0% | | 2% | | 4% | | 8% | | 14% | 21% | 30% | | 41% | 54% | 69% | | | | |
| Potato harvester | | | 2% | | 5% | | 9% | | 14% | | 19% | 25% | 30% | | 37% | 43% | 50% | | | | |
| Mower-conditioner | | | 1% | | 4% | | 8% | | 13% | | 18% | 24% | 31% | | 38% | 46% | 55% | | | | |
| Mower-conditioner (rotary) | | | 1% | | 3% | | 6% | | 10% | | 16% | 23% | 31% | | 41% | 52% | 64% | | | | |
| Rake | | | 2% | | 5% | | 8% | | 12% | | 17% | 22% | 27% | | 33% | 39% | 45% | | | | |
| Rectangular baler | | | 1% | | 4% | | 9% | | 15% | | 23% | 32% | 42% | | 54% | 66% | 80% | | | | |
| Large square baler | | | 1% | | 2% | | 4% | | 7% | | 10% | 14% | 18% | | 23% | 29% | 35% | | | | |
| Forage harvester (pull) | | | 1% | | 3% | | 7% | | 10% | | 15% | 20% | 26% | | 32% | 38% | 45% | | | | |
| Boom-type sprayer | | | 5% | | 12% | | 21% | | 31% | | 41% | 52% | 63% | | 76% | 88% | 101% | | | | |
| Air-carrier sprayer | | | 2% | | 5% | | 9% | | 14% | | 20% | 27% | 34% | | 42% | 51% | 61% | | | | |
| Bean puller-windrower | | | 2% | | 5% | | 9% | | 14% | | 20% | 27% | 34% | | 42% | 51% | 61% | | | | |
| Stalk chopper | | | 3% | | 8% | | 14% | | 20% | | 28% | 36% | 45% | | 54% | 64% | 74% | | | | |
| Forage blower | | | 1% | | 4% | | 9% | | 15% | | 22% | 31% | 40% | | 51% | 63% | 77% | | | | |
| Wagon | | | 1% | | 4% | | 7% | | 11% | | 16% | 21% | 27% | | 34% | 41% | 49% | | | | |
| Forage wagon | | | 2% | | 6% | | 10% | | 14% | | 19% | 24% | 29% | | 35% | 41% | 47% | | | | |
| Forage harvester (SP) | | | | 0% | | | 1% | | | 2% | | 4% | | 7% | | 10% | | 13% | 17% | 22% | 27% |
| Combine (SP) | | | | 0% | | | 1% | | | 2% | | 4% | | 6% | | 9% | | 12% | 16% | 20% | 25% |
| Windrower (SP) | | | | 1% | | | 2% | | | 5% | | 9% | | 14% | | 19% | | 26% | 35% | 44% | 54% |
| Cotton picker (SP) | | | | 1% | | | 4% | | | 9% | | 15% | | 23% | | 32% | | 42% | 53% | 66% | 79% |
| Mower (sickle) | | 1% | 3% | 6% | 10% | 14% | 19% | 25% | 31% | 38% | 46% | | | | | | | | | | |
| Mower (rotary) | | 0% | 2% | 4% | 7% | 11% | 16% | 22% | 28% | 36% | 44% | | | | | | | | | | |
| Large round baler | | 1% | 2% | 5% | 8% | 12% | 17% | 23% | 29% | 36% | 43% | | | | | | | | | | |
| Sugar beet harvester | | 3% | 7% | 12% | 18% | 24% | 30% | 37% | 44% | 51% | 59% | | | | | | | | | | |
| Rotary tiller | | 0% | 1% | 3% | 6% | 9% | 13% | 18% | 23% | 29% | 36% | | | | | | | | | | |
| Row crop planter | | 0% | 1% | 3% | 5% | 7% | 11% | 15% | 20% | 26% | 32% | | | | | | | | | | |
| Grain drill | | 0% | 1% | 3% | 5% | 7% | 11% | 15% | 20% | 26% | 32% | | | | | | | | | | |
| Fertilizer spreader | | 3% | 8% | 13% | 19% | 26% | 32% | 40% | 47% | 55% | 63% | | | | | | | | | | |

**Table 4.6:** ASABE Repair Costs Estimates Table for Tractors (ASABE, 2011)

| Type of Tractor | Accumulated hours | 1000 | 2000 | 3000 | 4000 | 5000 | 6000 | 7000 | 8000 | 9000 | 10000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Two-wheel drive tractor | | 1% | 3% | 6% | 11% | 18% | 25% | 34% | 45% | 57% | 70% |
| Four-wheel drive tractor | | 0% | 1% | 3% | 5% | 8% | 11% | 15% | 19% | 24% | 30% |

## Estimating Operating Hours Required

To calculate the total machinery operating cost for a specific process, the operating hours required for that process need to be estimated. Operating hours required is the number of acres covered divided by the field capacity of the machine being used. Field capacity or theoretical field capacity (TFC) is the rate at which a machine can cover a number of acres in acres per hour. TFC can be calculated by multiplying the machines width in feet, in field speed in miles per hour, and 8.25. The 8.25 is derived from dividing the number of square feet in an acre, 43,560, by the number of feet in a mile 5,280.

$$(TFC\ (A/hr)\ =\ width\ (ft)\ x\ speed\ (mi/hr)\ x\ (5{,}280\ ft/\ mi)/(43{,}560\ sq\ ft/A)$$

Or

$$TFC\ (A/hr)\ =\ width\ (ft)\ x\ speed\ (mi/hr)\ x\ 8.25$$

(4.1)

TFC does not account for turns, not utilizing the full width due to overlap, and other in field delays and is typically more than the actual effective field capacity (EFC). To calculate the EFC, TFC is multiplied by the field efficiency (FE). Field efficiency is the percentage of TFC that a machine achieves with real in field conditions. It accounts for the variations of in-field speed and machine performance, making adjustments, and any other time delays associated with an in-field process.

$$EFC(A/hr) = (width\ (ft)\ x\ speed\ (mph)\ x\ FE\%)\ /\ (8.25\ x\ 100)$$

(4.2)

### Machinery Cost Estimate Example for Chisel Plowing

An example of calculating total machinery cost for a specific production process would be calculating the cost to chisel plow a field, from the schedule of production events laid out in table 4.1. For this example, 300 acres will be chisel plowed as the first step in preparing the seedbed prior to planting. To plow the field, a 310 HP 4WD tractor will pull a 17 ft chisel plow. The labor rate is assumed to be $17/hour, interest rate is assumed to be 5%, fuel cost will be $2.50/gal, and inflation is assumed to be 3%. With these variables specified the theoretical and effective field cost can be calculated to determine the operating hours required to plow the field. The equation for theoretical field cost is;

$$TFC\ (A/hr) = (width\ (ft)\ x\ speed\ (mi/hr))\ /\ 8.25$$

(4.3)

The plow selected has a width of 17ft and an assumed in field speed of 6mph. TFC is the product of implement width and in-field speed divided by 8.25. This comes to a TFC of 14.42 acres plowed per hour.

$$TFC = (17\ (ft)\ x\ 7\ (mi/hr))\ /\ 8.25 = 14.42$$

(4.4)

Effective Field capacity can be calculated by multiplying the implement width by in-field speed by a field efficiency rating and then dividing that by 8.25. For the machinery combination selected field efficiency is estimated to be 85%. This results in an effective field capacity of 12.26 acres plowed per hour.

$$EFC \ = (17\ (ft) x\ 7\ (mi/hr)\ \ x\ 0.85\ )\ /\ 8.25 = 12.26$$

(4.5)

Operating Hours required can be calculated using the effective field capacity of the machinery combination. Hours required is the total number of acres plowed divided by the effective field capacity.

$$Op\ Hrs\ Req\ (hrs)\ = Acres/\ EFC$$

(4.6)

In this case it would be 300 acres divided by 12.26 acres/hour, which would result in 24.46 operating hours required to plow 300 acres.

$$Op\ Hrs\ Req\ (hrs) = 300/12.26 = 24.46 \text{ hrs}$$

(4.7)

## Total Machinery Operating Costs

Using the data from the grandchild module, implement performance, total machinery operating costs can be calculated for both the power source and implement. Machinery operating cost is the sum of; repair, fuel, lubrication, and labor costs.

$$Machinery\ Operating\ Cost\ (\$) = Repairs\ (\$) + Labor\ (\$) + Fuel\ and\ Lubrication\ (\$)$$

(4.8)

To calculate the repair costs per hour, which is the accumulated repair cost over the life of the machine divided by the total accumulated machine hours, the initial purchase price of the machine, average hours of use each year, and economic life of the machine will be needed.

$$Tractor\ Repair\ Costs\ (\$/hr) = (Initial\ Purchase\ Price\ (\$) x\ Repair\ Rate\ (\$))\ /\ Accumulated\ hrs\ (hrs)$$

And

$$Implement\ Repair\ Costs\ (\$/hr)\ = (Initial\ Purchase\ Price\ (\$) x\ Repair\ Rate\ (\$))\ /\ Accumulated\ hrs\ (hrs)$$

(4.9)

In this example the initial purchase prices for the tractor and plow is assumed to $365,000 and $85,000. 15 and 8 years are the economic lives of the machines and average hours of use per year is assumed to be 320 and 80. The accumulated hours are calculated to be 4800 and 640. Using the ASABE Repair Rates in tables 4.4 and 4.5, the accumulated repair costs are estimated to be 5% and 8% of initial purchase prices.

$$Tractor\ Repair\ Costs\ (\$/Op\ hr) = (365{,}000\ x\ 0.05\ (from\ Table\ 4.5))/\ (15\ x\ 320)$$

And

$$Implement\ Repair\ Costs\ (\$/Op\ hr)\ = (85{,}000\ x\ 0.08\ (from\ Table\ 4.5))/\ (8\ x\ 80)$$

(4.10)

Adding the repair cost per operating hour for the tractor and implement, 0.89 and 10.63, would result in a total repair cost of $11.5 per operating hour or a total repair cost of $281.29 for plowing 300 acres.

Fuel and lubrication costs can be calculated together. To calculate the fuel cost per acre an estimated fuel usage rate gallons/per acre is multiplied by the estimated cost of fuel. The equations for the tractor and implement differ somewhat in that fuel usage for tractors is measured in $/ operating hour and usage for implement is measured in gal/acre.

$$Tractor\ Fuel\ Costs\ (\$/Op\ Hr)\ = Fuel\ Usage\ Rate\ (gal/hr)\ x\ Fuel\ Cost\ (\$/gal)$$

And

$$Implement\ Fuel\ Costs\ (\$/acre)\ = (Fuel\ Usage\ Rate\ (gal/acre)\ x\ Fuel\ Cost\ (\$/gal)$$

(4.11)

Lubrication costs are assumed to be 15% of total fuel costs following Edwards (2011). Assuming the cost of fuel is $2.5/gal and usage rates are 13.64 gal/hour for the tractor and 1.1 gallons per acre for the implement, the total cost of fuel per operating hour would be $34.1 for the tractor and $2.75 per acre for the implement.

$$Tractor\ Fuel\ Costs\ (\$/hr)\ = 13.64\ x\ 2.5 = 34.1$$

$$\text{Total } Tractor\ Fuel\ Costs\ (\$) = 34.1\ x\ 24.46 = 834.09$$

And

$$Implement\ Fuel\ Costs\ (\$/acre)\ = 1.1\ x\ 2.5\ =\ 2.75$$

$$\text{Total } Implement\ Fuel\ Costs\ (\$) = 2.75\ x\ 300\ =\ 825$$

(4.12)

With the added lubrication costs, the total cost of fuel and lubrication for both pieces of machinery would be $1907.95 to plow the field.

$$Total\ Fuel\ and\ Lubrication\ Costs\ (\$)\ = ((0.15)\ x\ (834.08 + 825))\ + (834.08 + 825) = 1907.95$$

(4.13)

Labor costs are calculated by multiplying the labor rate $/hr by the number of operating hours required. However, labor hours exceed the time in field as machines have to be transported to and from the field. Edwards (2011) suggests using 1.1 and 1.2 as factors for accounting for the added time spent out of the field. In this example the added labor time is assumed to be 1.1 time the labor costs.

$$Labor\ Costs\ (\$/hr)\ = (Labor\ rate\ (\$/hr)\ x\ Op\ hrs\ Req\ (hrs))\ x\ 1.1$$

(4.14)

With a labor rate of 15 $/hr and an operating hours required to plow the field to be 24.46, the total labor costs for plowing comes out to $403.59.

$$Labor\ Costs\ (\$/hr)\ = (15\ x\ 24.46)\ x\ 1.1 = 403.59$$

(4.15)

To find the total Machinery Costs for plowing the 300 acre field, all the associated machinery operating costs are added together, which results in a total machinery operating cost of $2,592.83. In $/acre and $/Op Hr, total machinery costs would be $8.64 and $106.

$$Total\ Machinery\ Operating\ Costs\ (\$) = 281.29 + 1907.95 + 403.59 = 2{,}592.83$$

(4.12)

## Total Machinery Ownership Cost

Total Machinery Ownership Cost Calculations can be done by summing the total joint costs of interest and depreciation and the total cost of taxes, insurance, housing for a piece of machinery. The total joint cost of interest and depreciation, or capital recovery, is the sum of the total depreciation of the machine multiplied by a capital recovery factor and the salvage value multiplied the real interest rate.

$$Capital\ Recovery\ (\$) = (Total\ depreciation\ Value\ (\$) x\ CapitalRecovery\ Factor (From\ Table\ 4.3) + (Total\ Salvage\ Value\ x\ Real\ Interest\ Rate)$$

(4.13)

To calculate salvage value, the initial list price of the machinery is multiplied by the remaining Salvage value factor from tables 4.1 and 4.2. The remaining salvage value for tractors is the percent of the initial purchase price of the tractor reaming based on; tractor type, average annual machine hours, and age of the tractor.

$$Tractor\ Salvage\ Value\ (\$) = Initial\ Purchase\ Price\ (\$)\ x\ Remaining\ Value\ Factor\ (From\ Table\ 4.1)$$

(4.14)

Calculating the salvage value of an implement is almost the same except annual machine hours are not considered. Salvage value for implements is the remaining value, as a percentage of initial purchase price, which is found using table 4.2 based on the implement type and age of the machine.

$$\text{Implement Salvage Value (\$)} = \text{Initial Purchase Price (\$) x Remaining Value Factor (From Table 4.2)} \tag{4.15}$$

In the example calculation the tractor is a 310 HP 4WD tractor combined with a 17 ft chisel plow. The average annual hours of use for the tractor is 320 operating hours/year. The ages of both the tractor and implement are 2 and 5 years, with initial purchase prices set at $365,000 for the tractor and $85,000 for the plow. The salvage value for the tractor is calculated at 29% of the initial purchase price, which comes out to $215,350.

$$\text{Tractor Salvage Value (\$)} = 365{,}000 \text{ x } 0.59 = 215{,}350 \tag{4.16}$$

The Age of the implement is 5 years old with an initial purchase price of $85,000. Using Table 4.2 the reaming value factor of the implement is calculated at 35% of the initial purchase price, which results in a salvage value of $29,750.

$$\text{Implement Salvage Value (\$)} = 85{,}000 \text{ x } 0.35 = 29{,}750 \tag{4.17}$$

The total depreciation cost is found by subtracting the salvage value of the piece of machinery from the initial purchase price.

$$Tractor\ Depreciation\ Cost\ (\$) = \text{Initial Purchase Price of Tractor (\$) – Tractor Salvage Value (\$)}$$

$$Implement\ Depreciation\ Cost\ (\$) = \text{Initial Purchase Price of Implemenmt (\$) – Implement Salvage Value (\$)}$$

(4.18)

For the tractor and implement the total depreciation costs come out to $149,650 and $55,250.

$$Tractor\ Depreciation\ Cost\ (\$) = 365{,}000 – 215{,}350 = 149{,}650$$

$$Implement\ Depreciation\ Cost\ (\$) = 85{,}000 – 29{,}750 = 55{,}250$$

(4.19)

Real interest rate is the calculated inflation adjusted interest rate. To calculate real interest rate an inflation rate is subtracted from the actual interest rate.

*Real Interest Rate (%) = Actual Interest Rate (%) – Assumed Inflation Rate (%)*

(4.20)

With an actual interest rate of 55 and an assumed inflation rate of 3%, the real interest rate would be 2%.

$$Real\ Interest\ Rate\ (\%) = 5\% – 3\% = 2\%$$

(4.21)

The total joint costs of interest and depreciation, capital recovery, can be calculated using the above values and a capital recovery factor. The capital recovery factors for the tractor and implement can be found using table 4.3. The capital recovery factor is based on the real interest rate and the economic life of the machine. Assuming the economic life of the tractor is 15 years and the life of the implement is 8 year. The capital recovery factors for both are 0.078 and 0.137.

$$Tractor\ Capital\ Recovery\ (\$)\ = (149{,}650\ x\ 0.078) + (215{,}350\ \text{x}\ 2\%) = 15{,}979.70$$

$$Implement\ Capital\ Recovery\ (\$)\ = (55{,}250\ x\ 0.137)\ + (29{,}750\ x\ 2\%) = 8{,}164.25$$

(4.22)

The total capital recovery for the tractor and implement is calculated at $15,979.70 and $8,164.25, resulting in a total machinery capital recovery of $24,143 for the specific production year.

Property taxes, insurance, and housing costs are estimated as percentages of the average value of the machine Edwards (2011). To find the average value of the machine, the machine salvage value is subtracted from the initial purchase price and then the total is divided by two.

$$Average\ Value\ of\ Tractor = (\text{Tractor Purchase Price (\$) – Salvage Value (\$)}) / 2$$

Or

$$Average\ Value\ of\ Implement = (\text{Implement Purchase Price (\$) – Salvage Value (\$)}) / 2$$

(4.23)

Using the already calculated salvage values and initial purchase prices, the average values of the tractor and implement are calculated at $74,825 and $27,625, which sums to a total machinery average value of $102,450.

$$Average\ Value\ of\ Tractor = (365{,}000 – 215{,}350) / 2 = 74{,}825$$

$$Average\ Value\ of\ Implement = (85{,}000 – 29{,}750) / 2 = 27{,}625$$

(4.24)

With the total machinery average value, taxes insurance and housing (TIH) can be calculated in one equation. Property taxes are assumed to be 1% of the total average value, insurance 0.5% of the average value, and housing is estimated at 0.5% of the average value Edwards (2011). Total taxes, insurance, and housing can then be calculated as 2 % of the total average value of machinery, which results in a total TIH cost of $2,049.

Total ownership cost of machinery for a specific production year can then be calculated by summing the joint total cost of interest and depreciation and the total cost of taxes, insurance, and housing.

$$Total\ Ownership\ Costs\ = \text{Capital Recovery (\$)} + \text{Taxes Insurance and Housing Costs (\$)} \tag{4.25}$$

This results in a total cost of owning the specific machinery combination for a single production year of $26,192.

$$Total\ Ownership\ Costs\ = 24{,}143 + 2{,}049 = 26{,}192 \tag{4.26}$$

To calculate total machinery costs for chisel plowing a 300 acre field, total operating cost and total ownership costs are summed, resulting in a total machinery cost of

The total machinery cost for plowing 300 acres, assuming that the only activity completed with these equipment selections, is the sum of total operating and total ownership costs, which is $28,784.83

$Total\ Machinery\ Costs\ =$ Total Machinery Operating Cost (\$) + Total Machinery Ownership Costs (\$)

$$And$$

$$Total\ Machinery\ Costs\ = 2{,}592.83\ + 26{,}192 = 28{,}784.83 \tag{4.27}$$

## Farm Machinery Cost Model

At the time of writing this research, the GLADIS system is not fully functional. Preliminary models and corresponding data have been added into GLADIS and simulations have been run successfully, however, due to technical problems and the span of this research, the specific cost estimates that have been laid out thus far are not able to be modeled in GLADIS. To mitigate having a lack of resulting data from the combined models, a Microsoft® Excel® cost worksheet has been developed to estimate the specific farm machinery cost parameters this research covers. The macro enabled workbook will allow the user to build machinery combinations for in-field tasks and then estimate the total operating and ownership costs for all the machinery modeled.

## Database Development

Data for tractor performance and initial costs were combined into an excel database in order to aid in giving users the ability to see a distribution of data points from previous publications. In order to estimate cost and performance measures for farm machinery power sources, data on initial purchase prices, power source horsepower output, and fuel use were compiled. These data points were extracted from 3 specific publications; 2020/2021 Cost of Production: Farm Machinery, Machinery Cost Estimates: Tractors, and Machinery Cost Estimates (Manitoba, 2020, Lattz and Schnitkey, 2019, and Lazarus, 2012). An example excerpt of the excel table that houses all the tractor data used to estimate and determine suitable machinery combinations is in table 4.7 below.

**Table 4.7:** Excerpt from Tractor Database in the Farm Machinery Cost Model

| | (manitoba.ca/agriculture, 2020) | (UoILUC , 2019) | (Lazarus, 2012) | | (manitoba.ca/agriculture, 2020) | (Lazarus, 2012) | (UoILUC , 2019) |
|---|---|---|---|---|---|---|---|
| Tractor, Combine, Forage Harvester | Initial Price | Initial Price | Initial Price | PTO HP | Fuel Use | Fuel Use | Fuel Use |
| | $ | $ | $ | HP | gal/hr | gal/hr | gal/hr |
| 40 PTO HP 2WD | | | 25,000.00 | 40 | | 1.76 | |
| 60 PTO HP 2WD | | | 31,000.00 | 60 | | 2.64 | |
| 75 PTO HP 2WD | | | 54,000.00 | 75 | | 3.3 | |
| 85 PTO HP Tractor | | 114,488.00 | | 85 | | | 3.7 |
| 95 PTO HP Tractor | | 121,164.00 | | 95 | | | 4.1 |
| 100-119 PTO HP 2WD | 90,000.00 | | | 100-119 | 6.340128 | | |
| 110 PTO HP Tractor | 90,000.00 | 154,168.00 | | 110 | 6.340128 | | 4.8 |
| 120 PTO HP Tractor | | 161,538.00 | | 120 | | | 5.3 |
| 120+ PTO HP 2WD | 120,000.00 | | | 120+ | 7.396816 | | |
| 140 PTO HP Tractor | 120,000.00 | 177,022.00 | | 140 | 7.396816 | | 6.1 |
| 155 PTO HP Tractor | 120,000.00 | 186,904.00 | | 155 | 7.396816 | | 6.8 |
| 175 PTO HP Tractor | 120,000.00 | 196,751.00 | | 175 | 7.396816 | | 7.7 |
| 190 PTO HP Tractor | 120,000.00 | 241,267.00 | | 190 | 7.396816 | | 8.3 |
| 105 HP MFWD | | | 132,000.00 | 105 | | 4.62 | |
| 130 HP MFWD | | | 163,000.00 | 130 | | 5.72 | |
| 160 HP MFWD | | | 198,000.00 | 160 | | 7.04 | |
| 200 HP MFWD | | | 248,000.00 | 200 | | 8.8 | |
| 225 HP MFWD | | | 258,000.00 | 225 | | 9.9 | |
| 260 HP MFWD | | | 306,000.00 | 260 | | 11.44 | |
| 100-159 PTO HP FWA | 185,000.00 | | | 100-159 | 6.868472 | | |
| 160-224 PTO HP FWA | 240,000.00 | | | 160-224 | 9.510192 | | |
| 225 PTO HP Tractor, FWA | | 274,867.00 | | 225 | | | 9.9 |

Although there are 59 different tractor/harvester types in the data compiled, not all of them have corresponding price and performance data from each publication. This is not an issue as the model is truly meant for the individual user to model their own equipment, so the data point available is just to aid in estimating similar costs and performance measures.

The farm implement data was captured from the same 3 publications with the addition of 2 added publications from the Iowa State University extension department, Fuel Required for Field Operations and Estimating the Field Capacity of Farm Machines (Hanna, 2005 and 2016). The data points used to estimate implement performance were; width, initial purchase price, fuel usage rate, in field speed, field efficiency, effective field capacity, and the horsepower required to operate the implement. An example of the table used to record the data is below in table 4.8.

## **Table 4.8:** Excerpt from Implement Database in the Farm Machinery Cost Model

|  |  | (manitoba.ca/ agriculture, 2020) | (Lazarus, 2012) | (UoILUC , 2019) | (UoILUC , 2019) | (manitoba.ca/agriculture, 2020) | (Lazarus, 2012) | (UoILUC , 2019) | (Hanna, 2016) | (Hanna, 2016) | (UoILUC , 2019) | (Lazarus, 2012) | (Hanna, 2016) | (manitoba.ca/agriculture, 2020) | (Hanna, 2016) | (UoILUC , 2019) | (Lazarus, 2012) | (Lazarus, 2012) | (UoILUC , 2019) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Implement and Size | Width | Price | Price | Real Price | Price | Fuel Use | Fuel Use | Fuel Use | Fuel Use | Speed | Speed Using TFC | Speed using TFC | Field Efficency | Field Efficency | EFC Acres/hr | Acres/hr | Acres/hr | HP Req | HP Req |
|  | ft | $ | $ | $ | $ | gal/acre | gal/acre | gal/acre | (gal/acre) | MPH | MPH | MPH | Acres/hr | Acres/hr |  |  |  |  |  |
| Tillage |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Chisel plow |  |  |  |  |  |  |  |  |  | 5-7mph |  |  |  |  |  |  |  |  |  |
| Chisel plow 11 ft | 11 |  |  |  |  |  |  |  |  | 6 |  |  | 0.85 |  | 6.8 |  |  |  |  |
| Chisel Plow 12 ft | 12 |  |  | $ 25,327.60 | $ 22,024.00 |  |  | 0.8 | 1.1 | 7 | 4.95 |  |  |  |  | 7.2 |  |  | 140 |
| Chisel Plow 15 ft | 15 |  | $ 21,000.00 |  |  |  | 0.71 |  | 1.1 | 6 | 0 | 4.2515 |  |  |  |  | 7.73 | 130 HP MFWD |  |
| Chisel plow 17 ft | 17 |  |  |  |  |  |  |  | 1.1 | 6 |  |  | 0.83 |  | 10.3 |  |  |  |  |
| Chisel plow 21 ft | 21 |  |  | $ 51,175.00 | $ 44,500.00 |  |  | 0.8 | 1.1 | 6 | 4.940787402 |  | 0.83 |  | 12.7 | 12.6 |  |  | 240 |
| Chisel Plow 23 ft | 23 |  | $ 41,000.00 |  |  |  | 0.71 |  | 1.1 | 6 | 4.95 | 4.250543478 |  |  |  | 13.8 | 11.85 | 200 HP MFWD |  |
| Chisel Plow 27 ft. | 27 |  |  | $ 64,753.05 | $ 56,307.00 |  |  | 0.8 | 1.1 | 6 | 4.95 |  |  |  |  | 16.2 |  |  | 290 |
| Chisel Plow 30 ft. | 30 |  |  | $ 69,140.30 | $ 60,122.00 |  |  | 0.8 | 1.1 | 6 | 4.95 |  |  |  |  | 18 |  |  | 310 |
| Chisel Plow 35 ft. | 35 |  |  | $ 73,473.50 | $ 63,890.00 |  |  | 0.8 | 1.1 | 6 | 4.95 |  |  |  |  | 21 |  |  | 370 |
| Chisel Plow 37 Ft | 37 |  | $ 60,000.00 |  |  |  | 0.71 |  | 1.1 | 6 |  | 4.249864865 |  |  |  |  | 19.06 | 310 HP 4WD |  |
| Chisel Plow 40 ft. | 40 |  |  | $ 75,772.35 | $ 65,889.00 |  |  | 0.8 | 1.1 | 5 | 4.95 |  |  |  |  | 24 |  |  | 420 |
| Chisel plow 42 ft | 42 |  |  |  |  |  |  |  | 1.1 | 5 |  |  | 0.83 |  | 21.1 |  |  |  |  |
| Chisel Plow 44 ft. | 44 |  |  | $ 104,765.00 | $ 91,100.00 |  |  | 0.7 | 1.1 | 5 | 4.95 |  |  |  |  | 26.4 |  |  | 420 |
| Chisel Plow 47 ft. | 47 |  |  | $ 110,071.10 | $ 95,714.00 |  |  | 0.7 | 1.1 | 5 | 4.95 |  |  |  |  | 28.2 |  |  | 470 |
| Chisel Plow 55 ft. | 55 |  |  | $ 118,550.05 | $ 103,087.00 |  |  | 0.6 | 1.1 | 5 | 4.95 |  |  |  |  | 33 |  |  | 470 |
| Chisel Plow 57 Ft | 57 |  | $ 100,000.00 |  |  |  | 0.71 |  | 1.1 | 5 |  | 4.249473684 |  |  |  |  | 29.36 | 425 HP 4WD |  |
| Chisel Plow 61 ft. | 61 |  |  | $ 128,525.15 | $ 111,761.00 |  |  | 0.7 | 1.1 | 5 | 4.95 |  |  |  |  | 36.6 |  |  | 570 |

Data taken from the Iowa State University extension publications is the average field speeds, efficiencies, and effective capacities of different Iowa farm machines. 306 different farm implements were combined to create the database. Just like the tractor data, not all implement have corresponding data for each publication, but there is enough to get a good idea of what is to be expected for implement cost and performance.

The excel model built to replicate the GLADIS platform for the purposes of this work is mapped the same way a GLADIS simulation would be mapped. An example of the relationships used to estimate machinery costs at a basic level is shown below figure 4.1.

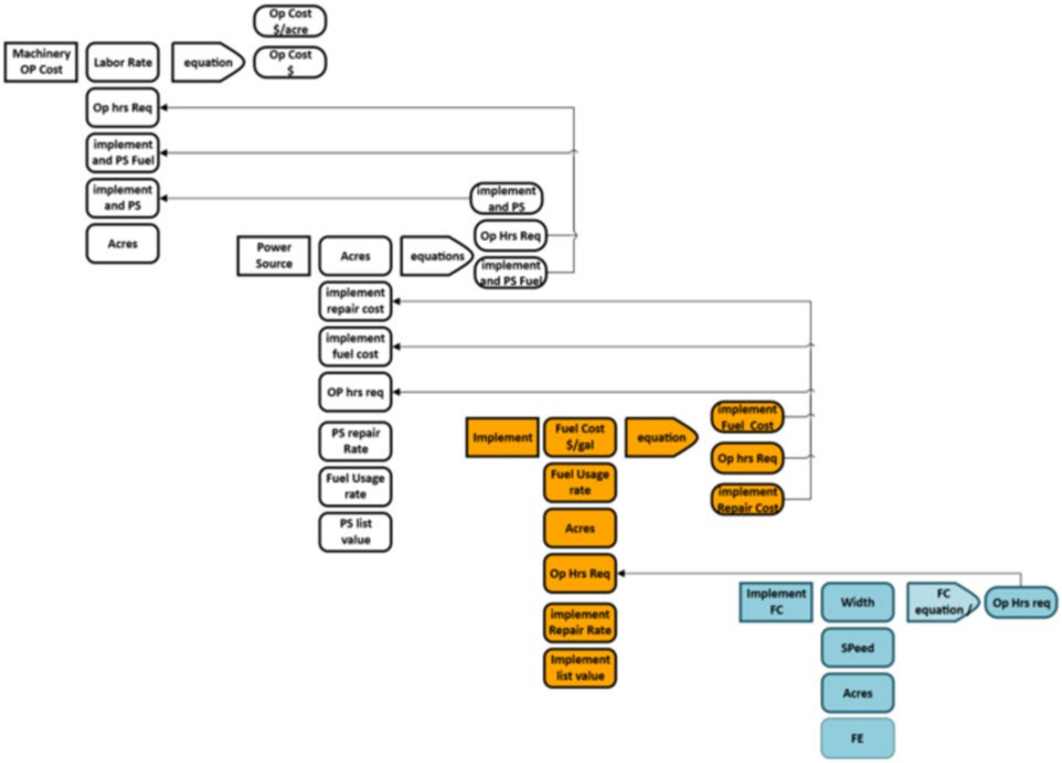
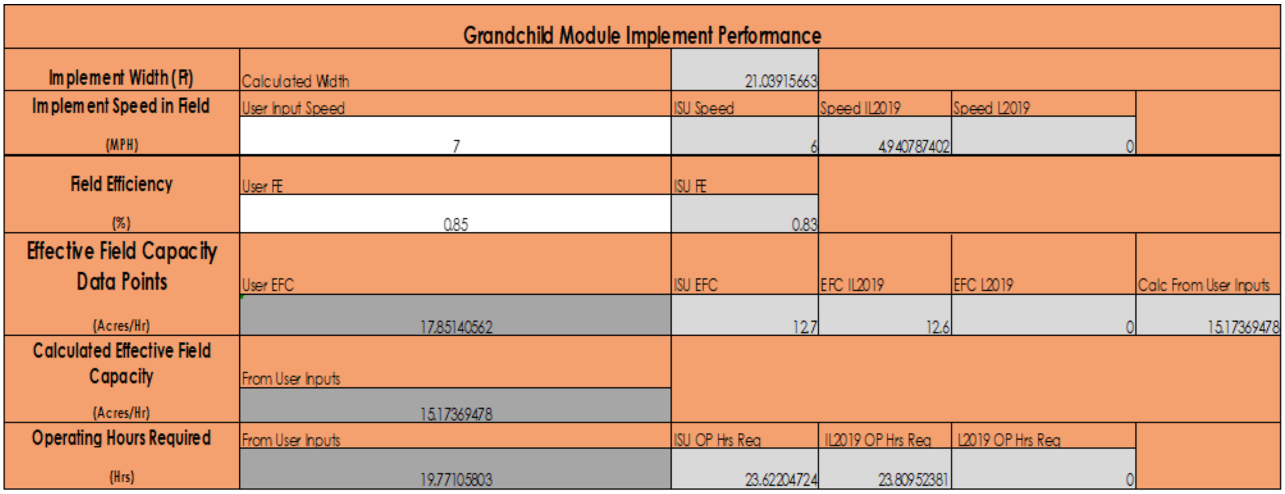


**Figure 4.1:** Relationship Mapping for Farm Machinery Cost Module

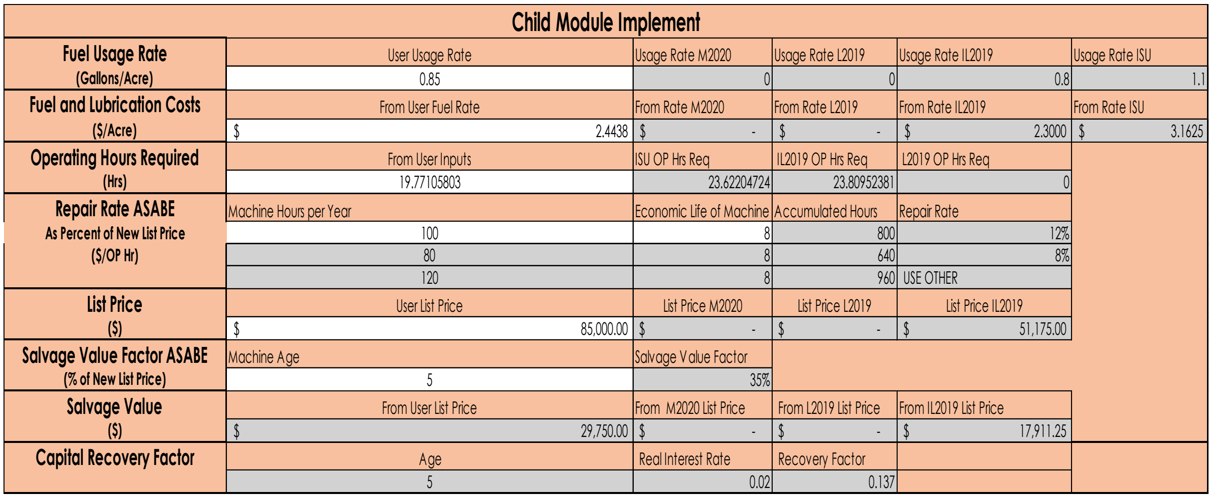
The first module built is the grandchild module. This module, which houses the implement performance data, calculates the operating hours required to complete an in-field task. Data, either input by the user or from the database created, on implement width, in-field speed, and field efficiency is used to calculate the theoretical field capacity (TFC) and effective field capacity (EFC). EFC is the operating hours required to complete an in-field task and is fed into the child module implement performance. An example of what the grandchild module looks like in the excel model is in figure 4.2.



| Grandchild Module Implement Performance | | | | | |
|---|---|---|---|---|---|
| Implement Width (Ft) | Calculated Width | 21.03915663 | | | |
| Implement Speed in Field (MPH) | User Input Speed | ISU Speed | Speed IL2019 | Speed L2019 | |
| | 7 | 6 | 4.940787402 | 0 | |
| Field Efficiency (%) | User FE | ISU FE | | | |
| | 0.85 | 0.83 | | | |
| Effective Field Capacity Data Points (Acres/Hr) | User EFC | ISU EFC | EFC IL2019 | EFC L2019 | Calc From User Inputs |
| | 17.85140562 | 12.7 | 12.6 | 0 | 15.17369478 |
| Calculated Effective Field Capacity (Acres/Hr) | From User Inputs | | | | |
| | 15.17369478 | | | | |
| Operating Hours Required (Hrs) | From User Inputs | ISU OP Hrs Req | IL2019 OP Hrs Req | L2019 OP Hrs Req | |
| | 19.77105803 | 23.62204724 | 23.80952381 | 0 | |

**Figure 4.2:** Grandchild Module Implement Performance in Excel Model

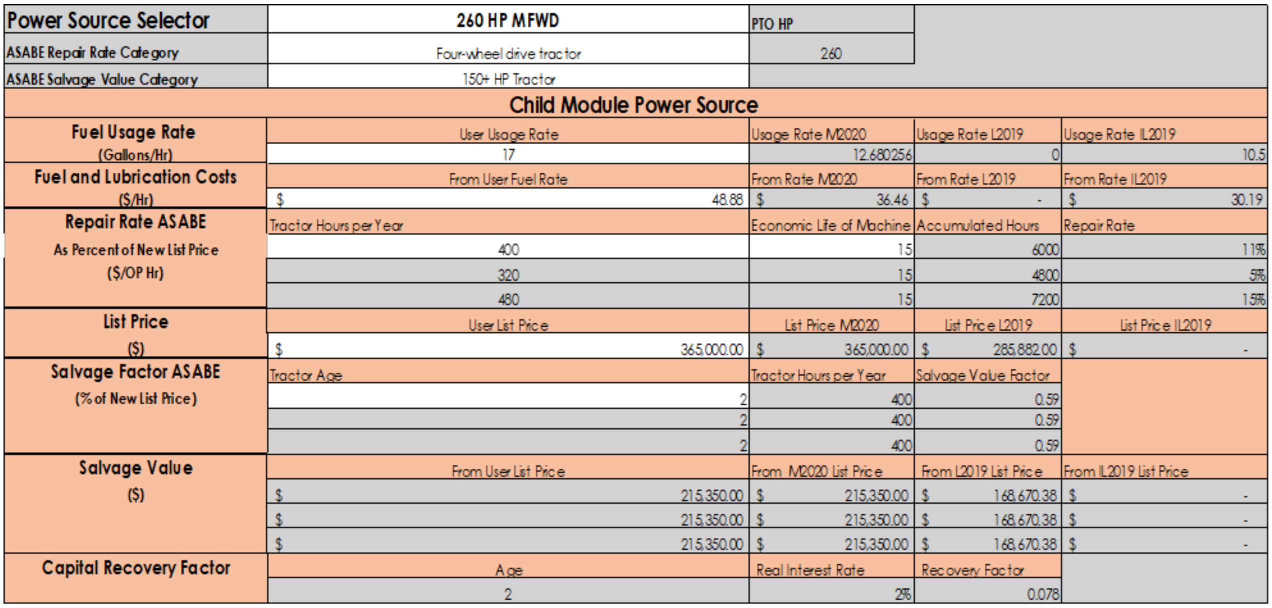
Based on the implement's field capacity, the implement costs for that field task is calculated next. The child module for an implement calculates; fuel and lubrication costs, the estimated repair costs, salvage value, and finally the capital recovery factor, which is used to determine the total joint costs of interest and depreciation. An example of the child module is below in figure 4.3.



| Child Module Implement | | | | | |
|---|---|---|---|---|---|
| **Fuel Usage Rate** (Gallons/Acre) | User Usage Rate | Usage Rate M2020 | Usage Rate L2019 | Usage Rate IL2019 | Usage Rate ISU |
| | 0.85 | 0 | 0 | 0.8 | 1.1 |
| **Fuel and Lubrication Costs** ($/Acre) | From User Fuel Rate | From Rate M2020 | From Rate L2019 | From Rate IL2019 | From Rate ISU |
| | $ 2.4438 | $ - | $ - | $ 2.3000 | $ 3.1625 |
| **Operating Hours Required** (Hrs) | From User Inputs | ISU OP Hrs Req | IL2019 OP Hrs Req | L2019 OP Hrs Req | |
| | 19.77105803 | 23.62204724 | 23.80952381 | 0 | |
| **Repair Rate ASABE** As Percent of New List Price ($/OP Hr) | Machine Hours per Year | Economic Life of Machine | Accumulated Hours | Repair Rate | |
| | 100 | 8 | 800 | 12% | |
| | 80 | 8 | 640 | 8% | |
| | 120 | 8 | 960 | USE OTHER | |
| **List Price** ($) | User List Price | List Price M2020 | List Price L2019 | List Price IL2019 | |
| | $ 85,000.00 | $ - | $ - | $ 51,175.00 | |
| **Salvage Value Factor ASABE** (% of New List Price) | Machine Age | Salvage Value Factor | | | |
| | 5 | 35% | | | |
| **Salvage Value** ($) | From User List Price | From M2020 List Price | From L2019 List Price | From IL2019 List Price | |
| | $ 29,750.00 | $ - | $ - | $ 17,911.25 | |
| **Capital Recovery Factor** | Age | Real Interest Rate | Recovery Factor | | |
| | 5 | 0.02 | 0.137 | | |

**Figure 4.3:** Child Module for Selected Implement in the Excel Model

The child module for the selected power source/ tractor calculates; fuel and lubrication costs, repair costs, salvage value and the corresponding capital recovery factor. An example of the child module for the power source selection is in figure 4.4.



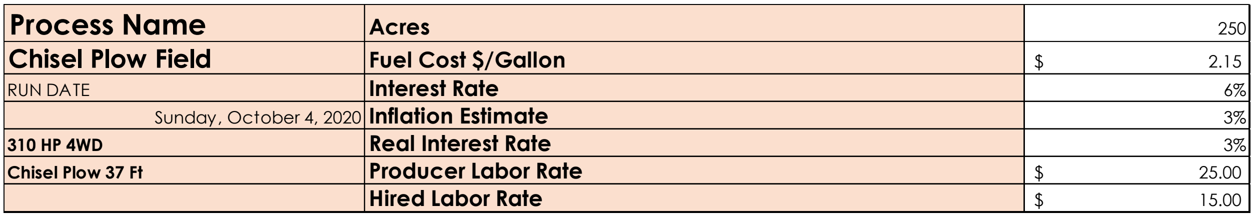
| Power Source Selector | 260 HP MFWD | PTO HP | | |
|---|---|---|---|---|
| ASABE Repair Rate Category | Four-wheel drive tractor | 260 | | |
| ASABE Salvage Value Category | 150+ HP Tractor | | | |
| **Child Module Power Source** | | | | |
| **Fuel Usage Rate** (Gallons/Hr) | User Usage Rate | Usage Rate M2020 | Usage Rate L2019 | Usage Rate IL2019 |
| | 17 | 12.680256 | 0 | 10.5 |
| **Fuel and Lubrication Costs** ($/Hr) | From User Fuel Rate | From Rate M2020 | From Rate L2019 | From Rate IL2019 |
| | $ 48.88 | $ 36.46 | $ - | $ 30.19 |
| **Repair Rate ASABE** As Percent of New List Price ($/OP Hr) | Tractor Hours per Year | Economic Life of Machine | Accumulated Hours | Repair Rate |
| | 400 | 15 | 6000 | 11% |
| | 320 | 15 | 4800 | 5% |
| | 480 | 15 | 7200 | 15% |
| **List Price** ($) | User List Price | List Price M2020 | List Price L2019 | List Price IL2019 |
| | $ 365,000.00 | $ 365,000.00 | $ 285,882.00 | $ - |
| **Salvage Factor ASABE** (% of New List Price) | Tractor Age | Tractor Hours per Year | Salvage Value Factor | |
| | 2 | 400 | 0.59 | |
| | 2 | 400 | 0.59 | |
| | 2 | 400 | 0.59 | |
| **Salvage Value** ($) | From User List Price | From M2020 List Price | From L2019 List Price | From IL2019 List Price |
| | $ 215,350.00 | $ 215,350.00 | $ 168,670.38 | $ - |
| | $ 215,350.00 | $ 215,350.00 | $ 168,670.38 | $ - |
| | $ 215,350.00 | $ 215,350.00 | $ 168,670.38 | $ - |
| **Capital Recovery Factor** | Age | Real Interest Rate | Recovery Factor | |
| | 2 | 2% | 0.078 | |

**Figure 4.4:** Child Module for Selected Power Source in the Excel Model

Just as in a GLADIS simulation, the model has to have the correct module mapping. In this case the solve plan would go from the grandchild module to the child modules and then finally solve for the parent module outputs. If estimating total farm machinery cost for a specified field task is the goal, then the first objective would be finding the effective field capacity of a given machinery selection, then from the field capacity the operating costs can be calculated, and then finally the ownership costs for the machinery can be added to the operating costs to calculate the total machinery costs.

## Estimating Farm Machinery Costs in the Excel Model

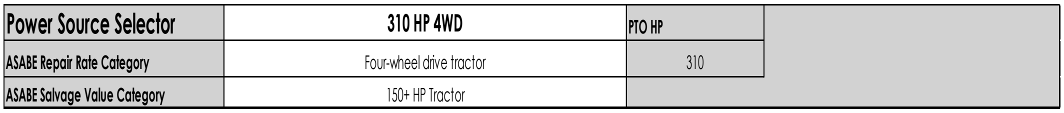
For the example field preparation timeline in table 4.1, an example cost calculation will be done with the excel model for chisel plowing a field. In the model the user can name the process being estimated and fill in the global variables that aren't specially housed in the modules. An example of the process name and global variables panel is shown if figure 4.5 below. The cells with no fill are the user input variables and they are; number of acres to be plowed, the cost of fuel, interest rate, estimate of the average inflation rate and corresponding real interest rate, the wage rate for the user, and the wage rate for any additional hired labor.



| | | |
|---|---|---|
| **Process Name** | **Acres** | 250 |
| **Chisel Plow Field** | **Fuel Cost $/Gallon** | $ 2.15 |
| RUN DATE | **Interest Rate** | 6% |
| Sunday, October 4, 2020 | **Inflation Estimate** | 3% |
| **310 HP 4WD** | **Real Interest Rate** | 3% |
| **Chisel Plow 37 Ft** | **Producer Labor Rate** | $ 25.00 |
| | **Hired Labor Rate** | $ 15.00 |

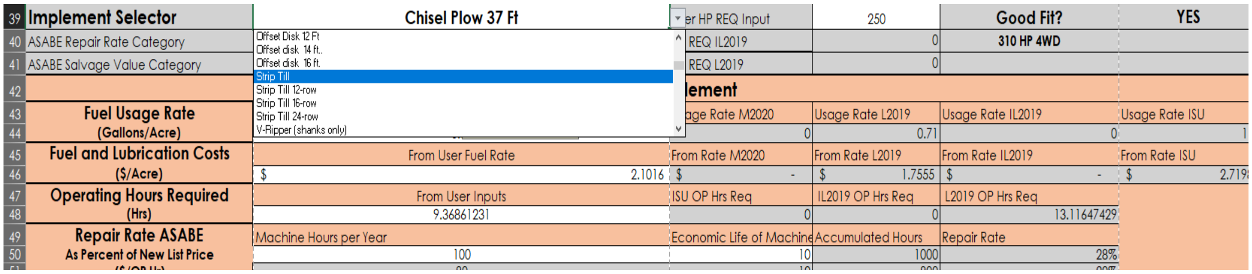
**Figure 4.5:** Process Title Panel and Global Variables

The power source and implement selections have to be input by the user, user inputs are the cells with no fill. For both the power source and implement used, there are several types of machinery that can be selected from the dropdown bar. Once a machinery combination is identified, the model will report whether or not the specific power source and implement combination is appropriate based on the horse power of the power source and horse power required to operate the implement.



| | | | |
|---|---|---|---|
| Power Source Selector | 310 HP 4WD | PTO HP | |
| ASABE Repair Rate Category | Four-wheel drive tractor | 310 | |
| ASABE Salvage Value Category | 150+ HP Tractor | | |

**Figure 4.6:** Power Source Panel in the Excel Model

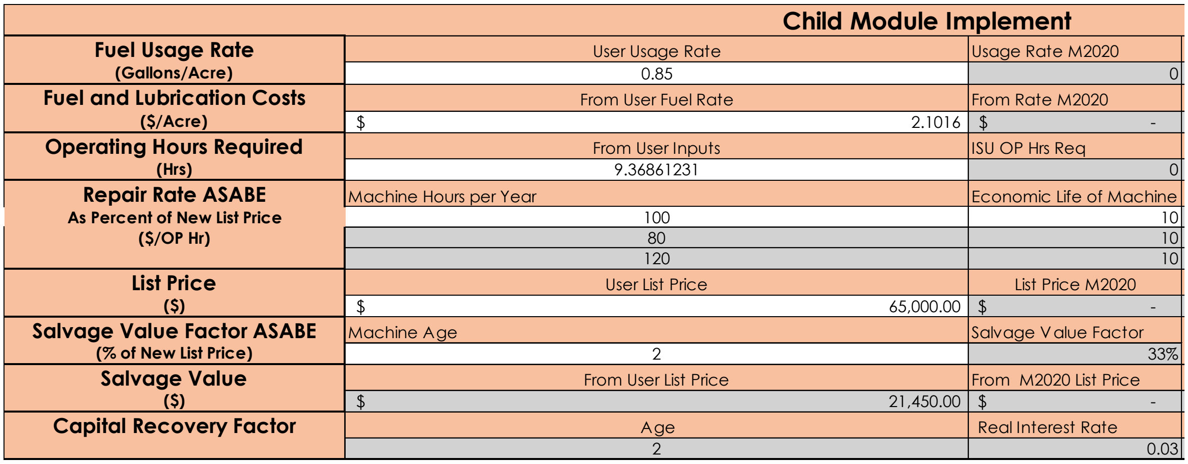


| | | | | | | |
|---|---|---|---|---|---|---|
| 39 | Implement Selector | Chisel Plow 37 Ft | er HP REQ Input | 250 | Good Fit? | YES |
| 40 | ASABE Repair Rate Category | | REQ IL2019 | 0 | 310 HP 4WD | |
| 41 | ASABE Salvage Value Category | | REQ L2019 | 0 | | |
| 42 | | | lement | | | |
| 43 | Fuel Usage Rate | | age Rate M2020 | Usage Rate L2019 | Usage Rate IL2019 | Usage Rate ISU |
| 44 | (Gallons/Acre) | | 0 | 0.71 | 0 | 1 |
| 45 | Fuel and Lubrication Costs | From User Fuel Rate | From Rate M2020 | From Rate L2019 | From Rate IL2019 | From Rate ISU |
| 46 | ($/Acre) | $ 2.1016 | $ - | $ 1.7555 | $ - | $ 2.719 |
| 47 | Operating Hours Required | From User Inputs | ISU OP Hrs Req | IL2019 OP Hrs Req | L2019 OP Hrs Req | |
| 48 | (Hrs) | 9.36861231 | 0 | 0 | 13.11647429 | |
| 49 | Repair Rate ASABE | Machine Hours per Year | Economic Life of Machine | Accumulated Hours | Repair Rate | |
| 50 | As Percent of New List Price | 100 | 10 | 1000 | 28% | |

**Figure 4.7:** Implement Selection Panel in the Excel Model

In the selection panels for the power source and implement, the user has to identify, based on the closest matching option, the ASABE repair rate and salvage value categories. For the 310 HP 4WD drive tractor selected the ASABE categories are; Four-wheel drive tractor and 150+ HP Tractor. These are used to estimate the repair rates, salvage value, and capital recovery factor.

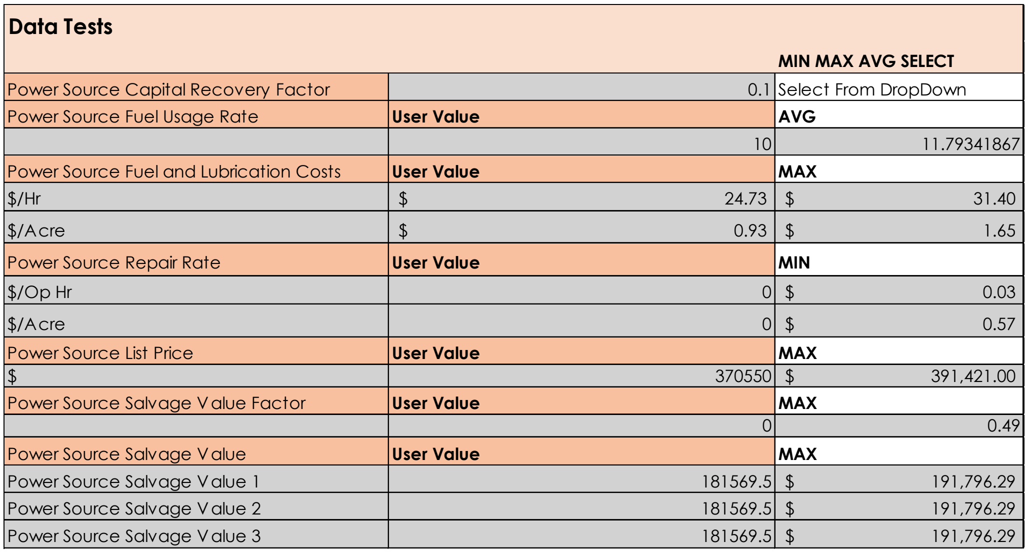
With these selections made the model can calculate the machinery costs based on the data point from previous publications, however they also have the option to create a more individualized model specific to their know data from previous years of other sources. In each module the user can fill in more specific data, which is in the cells that have no fill.



|  | Child Module Implement |  |
|---|---|---|
| **Fuel Usage Rate** (Gallons/Acre) | User Usage Rate | Usage Rate M2020 |
|  | 0.85 | 0 |
| **Fuel and Lubrication Costs** ($/Acre) | From User Fuel Rate | From Rate M2020 |
|  | $ 2.1016 | $ - |
| **Operating Hours Required** (Hrs) | From User Inputs | ISU OP Hrs Req |
|  | 9.36861231 | 0 |
| **Repair Rate ASABE** As Percent of New List Price ($/OP Hr) | Machine Hours per Year | Economic Life of Machine |
|  | 100 | 10 |
|  | 80 | 10 |
|  | 120 | 10 |
| **List Price** ($) | User List Price | List Price M2020 |
|  | $ 65,000.00 | $ - |
| **Salvage Value Factor ASABE** (% of New List Price) | Machine Age | Salvage Value Factor |
|  | 2 | 33% |
| **Salvage Value** ($) | From User List Price | From M2020 List Price |
|  | $ 21,450.00 | $ - |
| **Capital Recovery Factor** | Age | Real Interest Rate |
|  | 2 | 0.03 |

**Figure 4.8:** Example of the User Input Variables, In the Cells with no fill

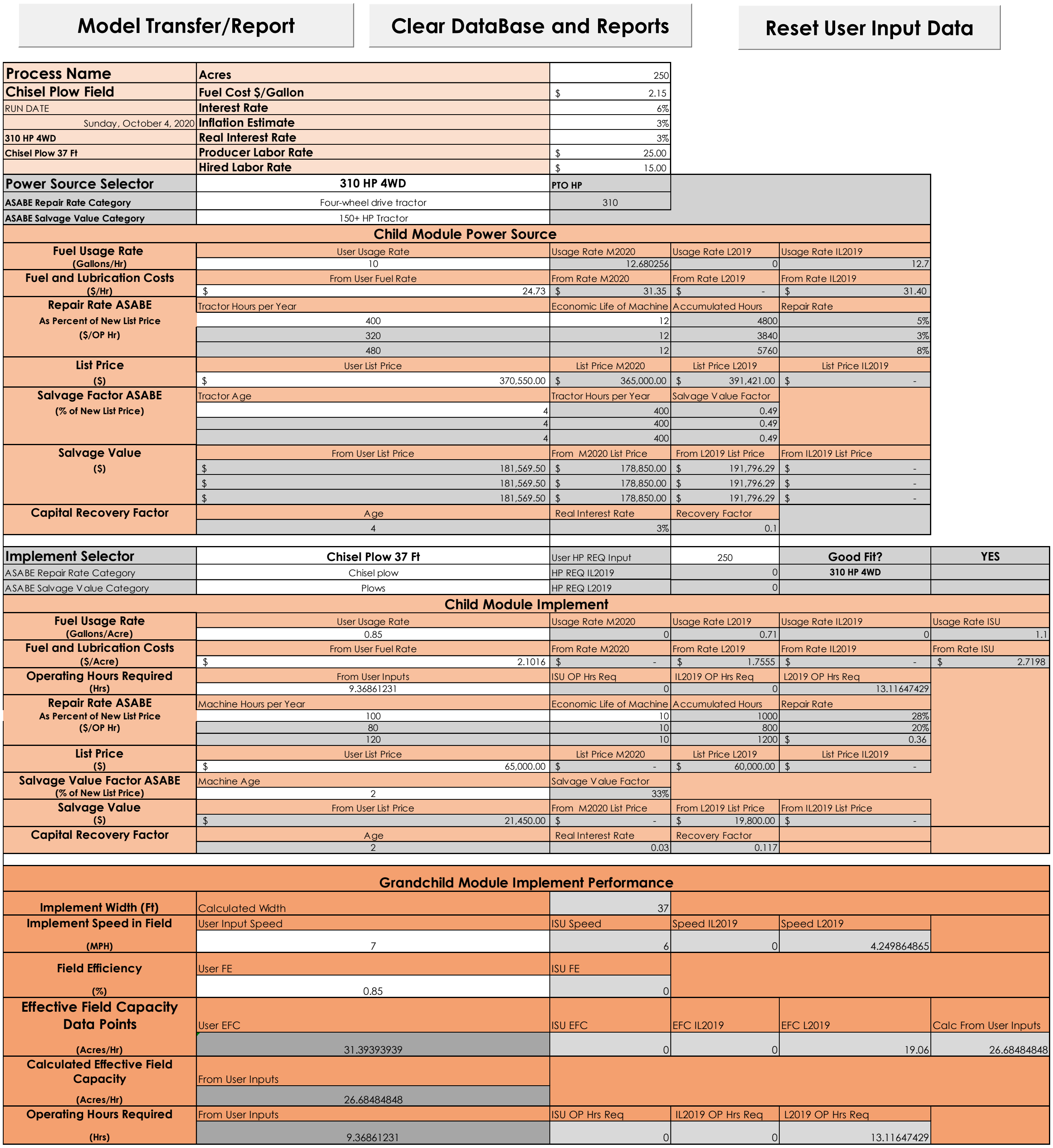
The user has the ability to factor in different variables to the overall machinery cost calculation. They can select the min, max, or avg values from the database. They can manipulate each variable to test what changing specific variables or combinations does to the cost output. This can give the user a better idea of how different conditions can affect their bottom line.



| **Data Tests** | | |
|---|---|---|
| | | **MIN MAX AVG SELECT** |
| Power Source Capital Recovery Factor | 0.1 | Select From DropDown |
| Power Source Fuel Usage Rate | **User Value** | **AVG** |
| | 10 | 11.79341867 |
| Power Source Fuel and Lubrication Costs | **User Value** | **MAX** |
| $/Hr | $ 24.73 | $ 31.40 |
| $/Acre | $ 0.93 | $ 1.65 |
| Power Source Repair Rate | **User Value** | **MIN** |
| $/Op Hr | 0 | $ 0.03 |
| $/Acre | 0 | $ 0.57 |
| Power Source List Price | **User Value** | **MAX** |
| $ | 370550 | $ 391,421.00 |
| Power Source Salvage Value Factor | **User Value** | **MAX** |
| | 0 | 0.49 |
| Power Source Salvage Value | **User Value** | **MAX** |
| Power Source Salvage Value 1 | 181569.5 | $ 191,796.29 |
| Power Source Salvage Value 2 | 181569.5 | $ 191,796.29 |
| Power Source Salvage Value 3 | 181569.5 | $ 191,796.29 |

**Figure 4.9:** Example of the Data Manipulation Available to the User

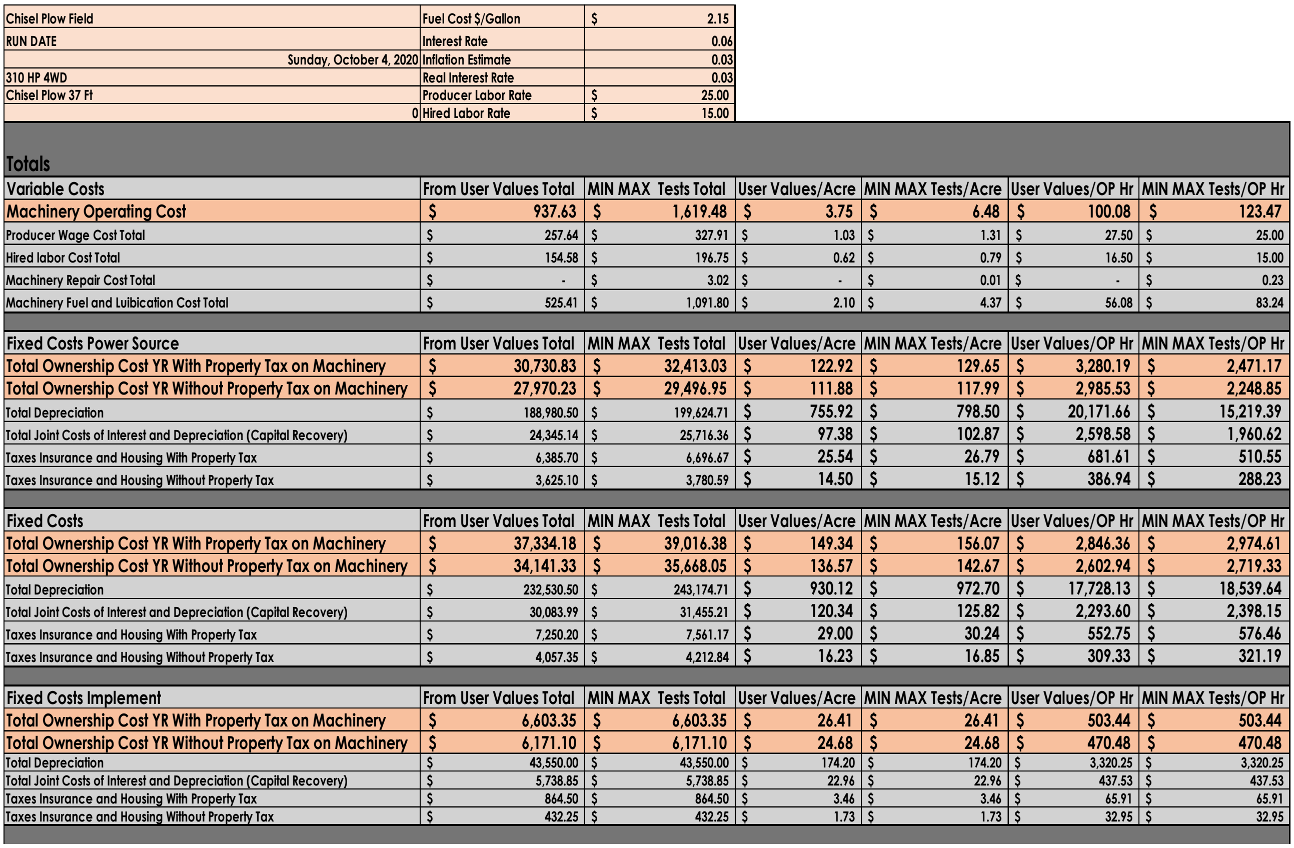
The model is complete from the user perspective after all the no-fill cells have data in them and any data manipulations the user wishes to do have been updated in the data test model. The user can then click the model transfer/report button, which transfers a copy of the created model to the model database tab. This database will house every model created to see the order in which all models were created and to record every machinery combination modeled. The complete model is shown below in figure 4.10.



| | | | | | |
|---|---|---|---|---|---|
| **Process Name** | **Acres** | 250 | | | |
| **Chisel Plow Field** | **Fuel Cost $/Gallon** | $ 2.15 | | | |
| RUN DATE | **Interest Rate** | 6% | | | |
| Sunday, October 4, 2020 | **Inflation Estimate** | 3% | | | |
| **310 HP 4WD** | **Real Interest Rate** | 3% | | | |
| **Chisel Plow 37 Ft** | **Producer Labor Rate** | $ 25.00 | | | |
| | **Hired Labor Rate** | $ 15.00 | | | |
| **Power Source Selector** | **310 HP 4WD** | **PTO HP** | | | |
| **ASABE Repair Rate Category** | Four-wheel drive tractor | 310 | | | |
| **ASABE Salvage Value Category** | 150+ HP Tractor | | | | |
| **Child Module Power Source** | | | | | |
| **Fuel Usage Rate** (Gallons/Hr) | User Usage Rate | Usage Rate M2020 | Usage Rate L2019 | Usage Rate IL2019 | |
| | 10 | 12.680256 | 0 | 12.7 | |
| **Fuel and Lubrication Costs** ($/Hr) | From User Fuel Rate | From Rate M2020 | From Rate L2019 | From Rate IL2019 | |
| | $ 24.73 | $ 31.35 | $ - | $ 31.40 | |
| **Repair Rate ASABE** As Percent of New List Price ($/OP Hr) | Tractor Hours per Year | Economic Life of Machine | Accumulated Hours | Repair Rate | |
| | 400 | 12 | 4800 | 5% | |
| | 320 | 12 | 3840 | 3% | |
| | 480 | 12 | 5760 | 8% | |
| **List Price** ($) | User List Price | List Price M2020 | List Price L2019 | List Price IL2019 | |
| | $ 370,550.00 | $ 365,000.00 | $ 391,421.00 | $ - | |
| **Salvage Factor ASABE** (% of New List Price) | Tractor Age | Tractor Hours per Year | Salvage Value Factor | | |
| | 4 | 400 | 0.49 | | |
| | 4 | 400 | 0.49 | | |
| | 4 | 400 | 0.49 | | |
| **Salvage Value** ($) | From User List Price | From M2020 List Price | From L2019 List Price | From IL2019 List Price | |
| | $ 181,569.50 | $ 178,850.00 | $ 191,796.29 | $ - | |
| | $ 181,569.50 | $ 178,850.00 | $ 191,796.29 | $ - | |
| | $ 181,569.50 | $ 178,850.00 | $ 191,796.29 | $ - | |
| **Capital Recovery Factor** | Age | Real Interest Rate | Recovery Factor | | |
| | 4 | 3% | 0.1 | | |
| **Implement Selector** | **Chisel Plow 37 Ft** | User HP REQ Input | 250 | **Good Fit?** | **YES** |
| ASABE Repair Rate Category | Chisel plow | HP REQ IL2019 | 0 | **310 HP 4WD** | |
| ASABE Salvage Value Category | Plows | HP REQ L2019 | 0 | | |
| **Child Module Implement** | | | | | |
| **Fuel Usage Rate** (Gallons/Acre) | User Usage Rate | Usage Rate M2020 | Usage Rate L2019 | Usage Rate IL2019 | Usage Rate ISU |
| | 0.85 | 0 | 0.71 | 0 | 1.1 |
| **Fuel and Lubrication Costs** ($/Acre) | From User Fuel Rate | From Rate M2020 | From Rate L2019 | From Rate IL2019 | From Rate ISU |
| | $ 2.1016 | $ - | $ 1.7555 | $ - | $ 2.7198 |
| **Operating Hours Required** (Hrs) | From User Inputs | ISU OP Hrs Req | IL2019 OP Hrs Req | L2019 OP Hrs Req | |
| | 9.36861231 | 0 | 0 | 13.11647429 | |
| **Repair Rate ASABE** As Percent of New List Price ($/OP Hr) | Machine Hours per Year | Economic Life of Machine | Accumulated Hours | Repair Rate | |
| | 100 | 10 | 1000 | 28% | |
| | 80 | 10 | 800 | 20% | |
| | 120 | 10 | 1200 | $ 0.36 | |
| **List Price** ($) | User List Price | List Price M2020 | List Price L2019 | List Price IL2019 | |
| | $ 65,000.00 | $ - | $ 60,000.00 | $ - | |
| **Salvage Value Factor ASABE** (% of New List Price) | Machine Age | Salvage Value Factor | | | |
| | 2 | 33% | | | |
| **Salvage Value** ($) | From User List Price | From M2020 List Price | From L2019 List Price | From IL2019 List Price | |
| | $ 21,450.00 | $ - | $ 19,800.00 | $ - | |
| **Capital Recovery Factor** | Age | Real Interest Rate | Recovery Factor | | |
| | 2 | 0.03 | 0.117 | | |
| **Grandchild Module Implement Performance** | | | | | |
| **Implement Width (Ft)** | Calculated Width | 37 | | | |
| **Implement Speed in Field** (MPH) | User Input Speed | ISU Speed | Speed IL2019 | Speed L2019 | |
| | 7 | 6 | 0 | 4.249864865 | |
| **Field Efficiency** (%) | User FE | ISU FE | | | |
| | 0.85 | 0 | | | |
| **Effective Field Capacity Data Points** (Acres/Hr) | User EFC | ISU EFC | EFC IL2019 | EFC L2019 | Calc From User Inputs |
| | 31.39393939 | 0 | 0 | 19.06 | 26.68484848 |
| **Calculated Effective Field Capacity** (Acres/Hr) | From User Inputs | | | | |
| | 26.68484848 | | | | |
| **Operating Hours Required** (Hrs) | From User Inputs | ISU OP Hrs Req | IL2019 OP Hrs Req | L2019 OP Hrs Req | |
| | 9.36861231 | 0 | 0 | 13.11647429 | |

**Figure 4.10:** Example of the Completed Model for Chisel Plowing

Transferring the created model also updates the CostsReport Tab and corresponding cost report table, which keeps a running total of all the costs for the combined models created by the user as well as the totals for each individual model created. The CostsReport layout is shown in figure 4.11 below, which has the machinery costs breakdown for chiseling plowing a 250 acre field.



| | | |
|---|---|---|
| Chisel Plow Field | Fuel Cost $/Gallon | $ 2.15 |
| RUN DATE | Interest Rate | 0.06 |
| Sunday, October 4, 2020 | Inflation Estimate | 0.03 |
| 310 HP 4WD | Real Interest Rate | 0.03 |
| Chisel Plow 37 Ft | Producer Labor Rate | $ 25.00 |
| 0 | Hired Labor Rate | $ 15.00 |

Totals

| Variable Costs | From User Values Total | MIN MAX Tests Total | User Values/Acre | MIN MAX Tests/Acre | User Values/OP Hr | MIN MAX Tests/OP Hr |
|---|---|---|---|---|---|---|
| Machinery Operating Cost | $ 937.63 | $ 1,619.48 | $ 3.75 | $ 6.48 | $ 100.08 | $ 123.47 |
| Producer Wage Cost Total | $ 257.64 | $ 327.91 | $ 1.03 | $ 1.31 | $ 27.50 | $ 25.00 |
| Hired labor Cost Total | $ 154.58 | $ 196.75 | $ 0.62 | $ 0.79 | $ 16.50 | $ 15.00 |
| Machinery Repair Cost Total | $ - | $ 3.02 | $ - | $ 0.01 | $ - | $ 0.23 |
| Machinery Fuel and Luibication Cost Total | $ 525.41 | $ 1,091.80 | $ 2.10 | $ 4.37 | $ 56.08 | $ 83.24 |
| | | | | | | |
| Fixed Costs Power Source | From User Values Total | MIN MAX Tests Total | User Values/Acre | MIN MAX Tests/Acre | User Values/OP Hr | MIN MAX Tests/OP Hr |
| Total Ownership Cost YR With Property Tax on Machinery | $ 30,730.83 | $ 32,413.03 | $ 122.92 | $ 129.65 | $ 3,280.19 | $ 2,471.17 |
| Total Ownership Cost YR Without Property Tax on Machinery | $ 27,970.23 | $ 29,496.95 | $ 111.88 | $ 117.99 | $ 2,985.53 | $ 2,248.85 |
| Total Depreciation | $ 188,980.50 | $ 199,624.71 | $ 755.92 | $ 798.50 | $ 20,171.66 | $ 15,219.39 |
| Total Joint Costs of Interest and Depreciation (Capital Recovery) | $ 24,345.14 | $ 25,716.36 | $ 97.38 | $ 102.87 | $ 2,598.58 | $ 1,960.62 |
| Taxes Insurance and Housing With Property Tax | $ 6,385.70 | $ 6,696.67 | $ 25.54 | $ 26.79 | $ 681.61 | $ 510.55 |
| Taxes Insurance and Housing Without Property Tax | $ 3,625.10 | $ 3,780.59 | $ 14.50 | $ 15.12 | $ 386.94 | $ 288.23 |
| | | | | | | |
| Fixed Costs | From User Values Total | MIN MAX Tests Total | User Values/Acre | MIN MAX Tests/Acre | User Values/OP Hr | MIN MAX Tests/OP Hr |
| Total Ownership Cost YR With Property Tax on Machinery | $ 37,334.18 | $ 39,016.38 | $ 149.34 | $ 156.07 | $ 2,846.36 | $ 2,974.61 |
| Total Ownership Cost YR Without Property Tax on Machinery | $ 34,141.33 | $ 35,668.05 | $ 136.57 | $ 142.67 | $ 2,602.94 | $ 2,719.33 |
| Total Depreciation | $ 232,530.50 | $ 243,174.71 | $ 930.12 | $ 972.70 | $ 17,728.13 | $ 18,539.64 |
| Total Joint Costs of Interest and Depreciation (Capital Recovery) | $ 30,083.99 | $ 31,455.21 | $ 120.34 | $ 125.82 | $ 2,293.60 | $ 2,398.15 |
| Taxes Insurance and Housing With Property Tax | $ 7,250.20 | $ 7,561.17 | $ 29.00 | $ 30.24 | $ 552.75 | $ 576.46 |
| Taxes Insurance and Housing Without Property Tax | $ 4,057.35 | $ 4,212.84 | $ 16.23 | $ 16.85 | $ 309.33 | $ 321.19 |
| | | | | | | |
| Fixed Costs Implement | From User Values Total | MIN MAX Tests Total | User Values/Acre | MIN MAX Tests/Acre | User Values/OP Hr | MIN MAX Tests/OP Hr |
| Total Ownership Cost YR With Property Tax on Machinery | $ 6,603.35 | $ 6,603.35 | $ 26.41 | $ 26.41 | $ 503.44 | $ 503.44 |
| Total Ownership Cost YR Without Property Tax on Machinery | $ 6,171.10 | $ 6,171.10 | $ 24.68 | $ 24.68 | $ 470.48 | $ 470.48 |
| Total Depreciation | $ 43,550.00 | $ 43,550.00 | $ 174.20 | $ 174.20 | $ 3,320.25 | $ 3,320.25 |
| Total Joint Costs of Interest and Depreciation (Capital Recovery) | $ 5,738.85 | $ 5,738.85 | $ 22.96 | $ 22.96 | $ 437.53 | $ 437.53 |
| Taxes Insurance and Housing With Property Tax | $ 864.50 | $ 864.50 | $ 3.46 | $ 3.46 | $ 65.91 | $ 65.91 |
| Taxes Insurance and Housing Without Property Tax | $ 432.25 | $ 432.25 | $ 1.73 | $ 1.73 | $ 32.95 | $ 32.95 |

**Figure 4.11:** CostsReport Tab Panels for the Chisel Plow Model

The total cost report shows the model name and machinery combination used to build the model. Costs are broken down into four categories; total machinery operating cost for the selection, fixed costs for the power source, total fixed costs for the combination, and fixed costs for the implement. Costs are reported for the results from the user input data as well as the data captured from the existing publications. The data from previous publications is reported as the minimum, maximum, or average of the range of data. They are broken down into a total cost, a per acre cost, and a per operating hour cost. The figure above shows the individual machinery combination costs. A running total is also in the CostsReport tab and totals the costs for all selection combinations modeled.

# CHAPTER V

# FINDINGS AND IMPLICATIONS FOR FUTURE RESEARCH

## Conclusions

The aim of this research was to leverage GLADIS 2.0 in creating an easy to use production cost estimation model that potential producers can implement to optimize their specific production strategy. The specific outcomes of this research were to create a conceptual basis for evaluating a BSC and identify critical production parameters to successfully grow and harvest switchgrass stands for biomass production. Utilizing the module based simulation process in GLADIS, a conceptual mapping for simulating production was created to model field processes and estimate the associated machinery costs. Although the GLADIS platform is not functional, a cost mapping system was developed that allowed producers to model their individual production processes and track total machinery ownership and operating costs.

The outcome of this research was a model that can estimate the fixed and variable machinery costs for any on-farm switchgrass production process, either developed using the individual's machinery costs and historical machinery performance data or cost and performance data from existing publications and models.

The model estimates the operating cost for a specific field activity by starting with an effective field capacity estimate for a specific machinery combination and then calculating the total fixed and operating costs for the implement and power source. The database created using existing estimations for machinery costs and performance data allows the user to rapidly develop multiple models for alternative switchgrass production strategies giving them the ability to assess current and possible future production scenarios without having previous records of cost and machinery performance measures. This results in the total fixed and variable costs for each field process modeled as well as the total costs for all of processes modeled. The user can then see specific costs for each process and evaluate the total costs for the overall production strategy used. With multiple models created, the user can analyze specific decision variables and their effect on each process giving them more insight into what may work best before making the decision to produce switchgrass or not.

## Limitations

The greatest limitation of this research is not being able to implement the base production scenario mapping and existing models into a functioning GLADIS platform. The goal of GLADIS 2.0 was to model a BSC and create a database of modules created by a variety of users, facing differing resource constraints, which would allow a user to easily and rapidly create simulations from all the existing modules housed in GLADIS. Without a functioning GLADIS platform, the user can still model other scenarios to evaluate many production strategies with the model created to mimic GLADIS, however they are limited in that they cannot utilize modules and simulations created by other users without having to manually create them in the workbook provided.

## Further Study

Future work should be focused on model integration into the GLADIS platform. Having a functional GLADIS platform, with the general BSC mapping and farm machinery performance and cost modules integrated, would be the first step in adding value to this research as it would be the basis for users to model their production scenarios and create and store public modules and simulations, therefore increasing the speed at which knowledge can be communicated and utilized on the platform. As more simulations and modules are stored in the database more options are generated to give users a greater set of tools in evaluating a variety production strategies.

For the crop production simulation aspect of GLADIS, the platform can't be complete without modeling the entire crop production process for switchgrass. This includes modules incorporating; robust farm machinery cost estimate capability, accurate yield estimations, harvest capacity requirements model, storage methods and dry matter loss outcomes, and method of delivering biomass to the bio-refinery.

Expanding simulation capabilities to include yield estimations, using existing crop growth models, based on regional environmental conditions as well as nutrient management protocols can aid producers in predicting total biomass produced in a growing season and add to better estimations of harvest and storage capacity requirements.

Developing methods for modeling dry matter loss during the on-farm storage phase is critical to estimating the overall biomass to be delivered to the refinery. Modules for method of storing and length of on-farm storage can help predict the added costs of dry-matter loss and further develop a cost effective logistics plan for delivering biomass.

Finally, the capability to model other crops being produced in an individual's operation would be necessary to perform the trade-off analysis critical to the decision of committing resources to new venture. If a producer can see accurate projected outcomes for both crops then they can make more informed decisions.

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# APPENDICES

# APPENDIX A

## Database Information

The images on the following pages are screen captures of the database that the farm machinery cost model draws machinery and implement price and performance data, which were taken from existing farm machinery cost estimation models.

**Appendix A Table 1:** Tractor Performance Data (Manitoba, 2020, Lattz and Schnitkey, 2019, and Lazarus, 2012)

| | (manitoba.ca/agriculture, 2020) | (UoILUC , 2019) | (Lazarus, 2012) | | (manitoba.ca/agriculture, 2020) | (Lazarus, 2012) | (UoILUC , 2019) |
|---|---|---|---|---|---|---|---|
| Tractor, Combine, Forage Harvester | Initial Price | Initial Price | Initial Price | PTO HP | Fuel Use | Fuel Use | Fuel Use |
| | $ | $ | $ | HP | gal/hr | gal/hr | gal/hr |
| 40 PTO HP 2WD | | | 25,000.00 | 40 | | 1.76 | |
| 60 PTO HP 2WD | | | 31,000.00 | 60 | | 2.64 | |
| 75 PTO HP 2WD | | | 54,000.00 | 75 | | 3.3 | |
| 85 PTO HP Tractor | | 114,488.00 | | 85 | | | 3.7 |
| 95 PTO HP Tractor | | 121,164.00 | | 95 | | | 4.1 |
| 100-119 PTO HP 2WD | 90,000.00 | | | 100-119 | 6.340128 | | |
| 110 PTO HP Tractor | 90,000.00 | 154,168.00 | | 110 | 6.340128 | | 4.8 |
| 120 PTO HP Tractor | | 161,538.00 | | 120 | | | 5.3 |
| 120+ PTO HP 2WD | 120,000.00 | | | 120+ | 7.396816 | | |
| 140 PTO HP Tractor | 120,000.00 | 177,022.00 | | 140 | 7.396816 | | 6.1 |
| 155 PTO HP Tractor | 120,000.00 | 186,904.00 | | 155 | 7.396816 | | 6.8 |
| 175 PTO HP Tractor | 120,000.00 | 196,751.00 | | 175 | 7.396816 | | 7.7 |
| 190 PTO HP Tractor | 120,000.00 | 241,267.00 | | 190 | 7.396816 | | 8.3 |
| 105 HP MFWD | | | 132,000.00 | 105 | | 4.62 | |
| 130 HP MFWD | | | 163,000.00 | 130 | | 5.72 | |
| 160 HP MFWD | | | 198,000.00 | 160 | | 7.04 | |
| 200 HP MFWD | | | 248,000.00 | 200 | | 8.8 | |
| 225 HP MFWD | | | 258,000.00 | 225 | | 9.9 | |
| 260 HP MFWD | | | 306,000.00 | 260 | | 11.44 | |
| 100-159 PTO HP FWA | 185,000.00 | | | 100-159 | 6.868472 | | |
| 160-224 PTO HP FWA | 240,000.00 | | | 160-224 | 9.510192 | | |
| 225 PTO HP Tractor, FWA | | 274,867.00 | | 225 | | | 9.9 |
| 225+ PTO HP FWA | 365,000.00 | | | 225+ | 12.680256 | | |
| 240 PTO HP Tractor, FWA | 365,000.00 | 285,882.00 | | 240 | 12.680256 | | 10.5 |
| 270 PTO HP Tractor, FWA | 365,000.00 | 365,010.00 | | 270 | 12.680256 | | 11.8 |
| 290 PTO HP Tractor, FWA | 365,000.00 | 391,421.00 | | 290 | 12.680256 | | 12.7 |
| 310 PTO HP Tractor, FWA | 365,000.00 | 410,256.00 | | 310 | 12.680256 | | 13.6 |
| 310 HP 4WD | | | 362,000.00 | 310 | | 13.64 | |
| 360 HP 4WD | 385,000.00 | | 350,000.00 | 313.2 | 16.642836 | 15.84 | |
| 370 Engine HP Tractor, 4WD | 385,000.00 | 358,736.00 | | 321.9 | 16.642836 | | 16.2 |
| 350-449 HP 4WD | 385,000.00 | | | | 16.642836 | | |
| 420 Engine HP Tractor, 4WD | 385,000.00 | 386,955.00 | | 365.4 | 16.642836 | | 18.4 |
| 425 HP 4WD | 385,000.00 | | 397,000.00 | 369.75 | 16.642836 | 18.7 | |
| 450-549 HP 4WD | 455,000.00 | | | | 20.077072 | | |
| 470 Engine HP Tractor, 4WD | 455,000.00 | 415,174.00 | | 408.9 | 20.077072 | | 20.6 |
| 550+ HP 4WD | 530,000.00 | | | 478.5 | 23.247136 | | |
| 570 Engine HP Tractor, 4WD | 530,000.00 | 487,819.00 | | 495.9 | 23.247136 | | 25 |
| 620 Engine HP Tractor, 4WD | 530,000.00 | 516,085.00 | | 539.4 | 23.247136 | | 27.2 |
| 260 HP Tracked Tractor | | | 335,000.00 | 226.2 | | 11.44 | |
| 350 HP Tracked Tractor | | | 416,000.00 | 304.5 | | 15.4 | |
| 300-359 HP Tracked Tractor | 435,000.00 | | | 261 | 12.680256 | | |
| 360-449 HP Tracked Tractor | 490,000.00 | | | 313.2 | 20.341244 | | |
| 450-549 HP Tracked Tractor | 580,000.00 | | | 391.5 | 29.05892 | | |
| 550-599 HP Tracked Tractor | 640,000.00 | | | 478.5 | 29.587264 | | |
| 600+ HP Tracked Tractor | 700,000.00 | | | 522 | 30.37978 | | |
| **Harvesters** | | | | | | | |
| 275 HP Combine | | | 326,000.00 | | | 12.1 | |
| SP Combine Class 5 Rotary < 300 HP | 420,000.00 | | | | 11.359396 | | |
| SP Combine Class 6 Rotary 301 - 360 HP | 485,000.00 | | | | 13.472772 | | |
| SP Combine Class 7 Rotary 361 - 420 HP | 530,000.00 | | | | 14.52946 | | |
| 375 HP Combine | | | 366,000.00 | | | 16.5 | |
| 440 HP Combine | | | 377,000.00 | | | 16.85 | |
| SP Combine Class 8 Rotary 421 - 500 HP | 580,000.00 | | | | 18.756212 | | |
| SP Combine Class 9 Rotary 501 - 560 HP | 610,000.00 | | | | 21.662104 | | |
| SP Combine Class 10 Rotary 561+ HP | 740,000.00 | | | | 23.77548 | | |
| SP Forage Harvester BaseUnit 400 HP | | | 356,000.00 | | | 9.6 | |
| SP Forage Harvester 400-599 HP | 495,000.00 | | | | 20.869588 | | |
| SP Forage Harvester BaseUnit 625 HP | | | 508,000.00 | | | 15 | |
| SP Forage Harvester 600-799 HP | 590,000.00 | | | | 27.209716 | | |
| SP Forage Harvester 800-899 HP | 675,000.00 | | | | 31.964812 | | |

**Appendix A Table 2:** Implement Price and Performance Data (Manitoba, 2020, Lattz and Schnitkey, 2019, and Lazarus, 2012)

| Implement and Size | Width | (manitoba.ca/agriculture, 2020) Price | (Lazarus, 2012) Price | (UoILUC , 2019) Real Price | (UoILUC , 2019) Price | (manitoba.ca/agriculture, 2020) Fuel Use | (Lazarus, 2012) Fuel Use | (UoILUC , 2019) Fuel Use | (Hanna, 2016) Fuel Use | (Hanna, 2016) Speed | (UoILUC , 2019) Speed Using T | (Lazarus, 2012) Speed using T | (Hanna, 2016) Field Efficer | (manitoba.ca/agriculture, 2020) Field Efficency | (Hanna, 2016) EFC Acres/h | (UoILUC , 2019) Acres/hr | (Lazarus, 2012) Acres/hr | (Lazarus, 2012) HP Req | (UoILUC , 2019) HP Req |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ft | $ | $ | $ | $ | gal/acre | gal/acre | gal/acre | (gal/acre) | MPH | MPH | MPH | Acres/hr | Acres/hr | | | | | |
| Tillage | | | | | | | | | | | | | | | | | | | |
| Chisel plow | | | | | | | | | | 5-7mph | | | | | | | | | |
| Chisel plow 11 ft | 11 | | | | | | | | | 6 | | | 0.85 | | 6.8 | | | | |
| Chisel Plow 12 ft | 12 | | | $ 25,327.60 | $ 22,024.00 | | | 0.8 | 1.1 | 7 | 4.95 | | | | | 7.2 | | | 140 |
| Chisel Plow 15 ft | 15 | | $ 21,000.00 | | | | 0.71 | | 1.1 | 6 | 0 | 4.2515 | | | | | 7.73 | 130 HP MFWD | |
| Chisel plow 17 ft | 17 | | | | | | | | 1.1 | 6 | | | 0.83 | | 10.3 | | | | |
| Chisel plow 21 ft | 21 | | | $ 51,175.00 | $ 44,500.00 | | | 0.8 | 1.1 | 6 | 4.940787402 | | 0.83 | | 12.7 | 12.6 | | | 240 |
| Chisel Plow 23 ft | 23 | | $ 41,000.00 | | | | 0.71 | | 1.1 | 6 | 4.95 | 4.250543478 | | | | 13.8 | 11.85 | 200 HP MFWD | |
| Chisel Plow 27 ft. | 27 | | | $ 64,753.05 | $ 56,307.00 | | | 0.8 | 1.1 | 6 | 4.95 | | | | | 16.2 | | | 290 |
| Chisel Plow 30 ft. | 30 | | | $ 69,140.30 | $ 60,122.00 | | | 0.8 | 1.1 | 6 | 4.95 | | | | | 18 | | | 310 |
| Chisel Plow 35 ft. | 35 | | | $ 73,473.50 | $ 63,890.00 | | | 0.8 | 1.1 | 6 | 4.95 | | | | | 21 | | | 370 |
| Chisel Plow 37 Ft | 37 | | $ 60,000.00 | | | | 0.71 | | 1.1 | 6 | | 4.249864865 | | | | | 19.06 | 310 HP 4WD | |
| Chisel Plow 40 ft. | 40 | | | $ 75,772.35 | $ 65,889.00 | | | 0.8 | 1.1 | 5 | 4.95 | | | | | 24 | | | 420 |
| Chisel plow 42 ft | 42 | | | | | | | | 1.1 | 5 | | | 0.83 | | 21.1 | | | | |
| Chisel Plow 44 ft. | 44 | | | $ 104,765.00 | $ 91,100.00 | | | 0.7 | 1.1 | 5 | 4.95 | | | | | 26.4 | | | 420 |
| Chisel Plow 47 ft. | 47 | | | $ 110,071.10 | $ 95,714.00 | | | 0.7 | 1.1 | 5 | 4.95 | | | | | 28.2 | | | 470 |
| Chisel Plow 55 ft. | 55 | | | $ 118,550.05 | $ 103,087.00 | | | 0.6 | 1.1 | 5 | 4.95 | | | | | 33 | | | 470 |
| Chisel Plow 57 Ft | 57 | | $ 100,000.00 | | | | 0.71 | | 1.1 | 5 | | 4.249473684 | | | | | 29.36 | 425 HP 4WD | |
| Chisel Plow 61 ft. | 61 | | | $ 128,525.15 | $ 111,761.00 | | | 0.7 | 1.1 | 5 | 4.95 | | | | | 36.6 | | | 570 |
| Disk Primary | | | | | | | | | | | | | | | | | | | |
| Disk, primary 21 ft | 21 | | | | | | | | 1.3 | 5 | | | 0.83 | | 10.6 | | | | |
| Disk, primary 24 ft | 24 | | | | | | | | 1.3 | 5 | | | 0.83 | | 12.1 | | | | |
| Disk, primary 30 ft | 30 | | | | | | | | 1.3 | 5 | | | 0.83 | | 15.1 | | | | |
| Disk, primary 36 ft | 36 | | | | | | | | 1.3 | 5 | | | 0.8 | | 17.5 | | | | |
| Disk, primary 40 ft | 40 | | | | | | | | 1.3 | 5 | | | 0.8 | | 19.4 | | | | |
| Disk, primary 44 ft | 44 | | | | | | | | 1.3 | 4.5 | | | 0.8 | | 19.2 | | | | |
| Disk Secondary | | | | | | | | | | | | | | | | | | | |
| Disk, secondary 21 ft | 21 | | | | | | | | 0.65 | 6 | | | 0.83 | | 12.7 | | | | |
| Disk, secondary 24 ft | 24 | | | | | | | | 0.65 | 6 | | | 0.83 | | 14.5 | | | | |
| Disk, secondary 30 ft | 30 | | | | | | | | 0.65 | 6 | | | 0.83 | | 18.1 | | | | |
| Disk, secondary 36 ft | 36 | | | | | | | | 0.65 | 6 | | | 0.8 | | 20.9 | | | | |
| Disk, secondary 40 ft | 40 | | | | | | | | 0.65 | 6 | | | 0.8 | | 23.3 | | | | |
| Disk, secondary 44 ft | 44 | | | | | | | | 0.65 | 5.5 | | | 0.8 | | 23.5 | | | | |
| Disk, secondary 49 ft | 49 | | | | | | | | 0.65 | 5 | | | 0.8 | | 23.8 | | | | |
| Disk Ripper (disk, chisel, rolling basket) | | | | | | | | | | | | | | | | | | | |
| Disk Ripper 12 ft | 12 | | | $ 54,265.05 | $ 47,187.00 | | | 2.1 | | | 4.95 | | | | | 7.2 | | | 225 |
| Disk Ripper 17 Ft | 17 | | | $ 69,318.55 | $ 60,277.00 | | | 2.1 | | | 4.95 | | | | | 10.2 | | | 310 |
| Disk Ripper 22 Ft | 22 | | | $ 109,105.10 | $ 94,874.00 | | | 1.9 | | | 4.95 | | | | | 13.2 | | | 370 |
| 260 HP Tracked Tractor | 27 | | | $ 126,564.40 | $ 110,056.00 | | | 1.5 | | | 4.95 | | | | | 16.2 | | | 370 |
| Subsoiler | | | | | | | | | | | | | | | | | | | |
| Subsoiler 5-30" | 12 | | | | | | | | 1.7 | 5 | | | 0.85 | | 6.4 | | | | |
| Subsoiler 7-24" | 14 | | | | | | | | 1.7 | 5 | | | 0.83 | | 7 | | | | |
| Subsoiler 7-30" | 17 | | | | | | | | 1.7 | 5 | | | 0.83 | | 8.8 | | | | |
| Subsoiler 9-24" | 18 | | | | | | | | 1.7 | 5 | | | 0.83 | | 9.1 | | | | |
| Vertical tillage, rolling basket | | | | | | | | | | | | | | | | | | | |
| Vertical tillage, rolling basket 21 ft 9 in | 21.75 | | | $ 88,735.15 | $ 77,161.00 | | | 0.4 | | | 7.434482759 | | | | | 19.6 | | | 190 |
| Vertical tillage, rolling basket 25 ft 5 in | 25.42 | | | $ 101,886.55 | $ 88,597.00 | | | 0.5 | | | 7.432140047 | | | | | 22.9 | | | 240 |
| Vertical tillage, rolling basket 30 ft 3 in | 30.25 | | | $ 121,095.00 | $ 105,300.00 | | | 0.4 | | | 7.418181818 | | | | | 27.2 | | | 270 |
| Vertical tillage, rolling basket 33 ft 10 in | 33.83 | | | $ 135,752.90 | $ 118,046.00 | | | 0.4 | | | 7.41353828 | | | | | 30.4 | | | 290 |
| Vertical tillage, rolling basket 43 ft 6 in | 43.5 | | | $ 170,890.00 | $ 148,600.00 | | | 0.4 | | | 7.434482759 | | | | | 39.2 | | | 370 |
| Vertical tillage, rolling basket 49 ft 6 in | 49.5 | | | $ 207,510.60 | $ 180,444.00 | | | 0.5 | | | 7.433333333 | | | | | 44.6 | | | 570 |

**Appendix A Table 2 (continued):** Implement Price and Performance Data (Manitoba, 2020, Lattz and Schnitkey, 2019, and Lazarus, 2012)

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Vertical tillage, rolling basket 49 ft 6 in | 49.5 | | $ 207,510.60 | $ 180,444.00 | | 0.5 | | | 7.433333333 | | | | 44.6 | | 570 |
| Moldboard plow | | | | | | | | | | | | | | | |
| Moldboard plow 6 bottom | 9 | $ 35,000.00 | | | 1.32 | | 1.7 | 5 | | 3.8225 | | | | 4.17 | 130 HP MFWD |
| Moldboard plow 7 bottom | 10.5 | | $ 62,913.05 | $ 54,707.00 | | 2.1 | 1.7 | 5 | | | | | 4.7 | | 225 |
| Moldboard Plow 8 Bottom-18, 12 Ft | 12 | $ 45,000.00 | | | 1.32 | | 1.7 | | | 3.8225 | | | | 5.56 | 160 HP MFWD |
| Moldboard plow 9 bottom | 13.5 | | $ 88,762.75 | $ 77,185.00 | | 1.9 | 1.7 | 5 | | | | | 6.1 | | 270 |
| Moldboard plow 10 bottom | 15 | | $ 98,417.00 | $ 85,580.00 | | 1.9 | 1.7 | 5 | | | | | 6.8 | | 290 |
| Moldboard Plow 6 row | 8 | | | | | | 1.7 | 5 | | | 0.85 | 4.1 | | | |
| Moldboard Plow 8 row | 12 | | | | | | 1.7 | 5 | | | 0.85 | 6.2 | | | |
| Moldboard Plow 10 row | 15 | | | | | | 1.7 | 5 | | | 0.83 | 7.5 | | | |
| Mulch tiller (disk, chisel shanks) | | | | | | | | | | | | | | | |
| Mulch tiller 6 ft | 6 | | $ 12,592.50 | $ 10,950.00 | | 1.4 | | | 4.125 | | | | 3 | | 95 |
| Mulch tiller 8 ft | 8 | | $ 14,950.00 | $ 13,000.00 | | 0.9 | | | 5.15625 | | | | 5 | | 110 |
| Mulch tiller 11 ft. 3 in. | 11.25 | | $ 24,547.90 | $ 21,346.00 | | 0.9 | | | 4.106666667 | | | | 5.6 | | 120 |
| Mulch tiller 13 ft. 9 in. | 13.75 | | $ 30,416.35 | $ 26,449.00 | | 1.1 | | | 4.14 | | | | 6.9 | | 175 |
| Mulch tiller 16 ft. 3 in. | 16.25 | | $ 34,236.65 | $ 29,771.00 | | 1.2 | | | 4.112307692 | | | | 8.1 | | 225 |
| Mulch tiller 18 ft. 9 in. | 18.75 | | $ 51,432.60 | $ 44,724.00 | | 1.3 | | | 4.136 | | | | 9.4 | | 270 |
| Mulch tiller 21 ft 3 in. | 21.25 | | $ 53,941.90 | $ 46,906.00 | | 1.2 | | | 4.115294118 | | | | 10.6 | | 290 |
| Offset disk | | | | | | | | 4.5-5 mph | | | | | | | |
| Offset disk 10 ft | 10 | | $ 30,876.35 | $ 26,849.00 | | 0.8 | 0.85 | 5 | 4.95 | | | | 6 | | 110 |
| Offset Disk 12 Ft | 12 | $ 24,000.00 | | | 0.83 | | 0.85 | | | 3.8225 | | | | 5.56 | 105 HP MFWD |
| Offset disk 14 ft.. | 14 | | $ 33,921.55 | $ 29,497.00 | | 0.7 | 0.85 | 4.5 | 4.95 | | | | 8.4 | | 140 |
| Offset disk 16 ft. | 16 | | $ 35,890.35 | $ 31,209.00 | | 0.7 | 0.85 | 4.5 | 4.95 | | | | 9.6 | | 155 |
| Strip Till | | | | | | | | | | | | | | | |
| Strip Till 12-row | | | $ 99,407.15 | $ 86,441.00 | | 0.7 | | | | | | | 17.5 | | 290 |
| Strip Till 16-row | | | $ 125,221.20 | $ 108,888.00 | | 0.6 | | | | | | | 23.3 | | 310 |
| Strip Till 24-row | | | $ 119,600.00 | $ 104,000.00 | | 0.7 | | | | | | | 34.9 | | 570 |
| V-Ripper (shanks only) | | | | | | | | | | | | | | | |
| V-Ripper 25 " O.C., 10 Ft | 10 | $ 16,000.00 | | | 1.1 | | 1.7 | | | 5.0985 | | | | 6.18 | 160 HP MFWD |
| V-Ripper 10 ft 6 in | 10.5 | | $ 8,245.50 | $ 7,170.00 | | 0.9 | 1.7 | | 4.164285714 | | | | 5.3 | | 110 |
| V-Ripper 14 ft 7 in | 14.58 | | $ 10,225.80 | $ 8,892.00 | | 1.4 | 1.7 | | 4.130658436 | | | | 7.3 | | 240 |
| V-Ripper 15 ft | 15 | | $ 15,848.15 | $ 13,781.00 | | 1.5 | 1.7 | | 4.125 | | | | 7.5 | | 270 |
| V-Ripper 30 " O.C., 17 Ft | 17 | $ 21,000.00 | | | 1.1 | | 1.7 | | | 5.100441176 | | | | 10.51 | 260 HP MFWD |
| V-Ripper 18 ft 4 in | 18.3 | | $ 19,092.30 | $ 16,602.00 | | 1.5 | 1.7 | | 4.147540984 | | | | 9.2 | | 310 |
| V-Ripper 25 " O.C., 18 Ft | 18 | $ 25,000.00 | | | 1.1 | | 1.7 | | | 5.10125 | | | | 11.13 | 260 HP MFWD |
| V-Ripper 21 ft 8 in | 21.67 | | $ 23,052.90 | $ 20,046.00 | | 1.7 | 1.7 | | 4.111675127 | | | | 10.8 | | 420 |
| V-Ripper 30 " O.C., 22.5 Ft | 22.5 | $ 26,000.00 | | | 1.1 | | 1.7 | | | 5.100333333 | | | | 13.91 | 360 HP 4WD |
| Mulch finisher (disk, chisel, and drag) | | | | | | | | | | | | | | | |
| Mulch finisher 21 ft 9" | 21.75 | | $ 77,014.35 | $ 66,969.00 | | 0.8 | | | 4.968965517 | | | | 13.1 | | 225 |
| Mulch finisher 24 ft 9" | 24.75 | | $ 86,122.35 | $ 74,889.00 | | 0.7 | | | 4.966666667 | | | | 14.9 | | 240 |
| Mulch finisher 27 ft 9" | 27.75 | | $ 98,716.00 | $ 85,840.00 | | 0.6 | | | 4.964864865 | | | | 16.7 | | 240 |
| Mulch finisher 30 ft 9" | 30.75 | | $ 110,658.75 | $ 96,225.00 | | 0.6 | | | 4.963414634 | | | | 18.5 | | 270 |
| Mulch finisher 33 ft 9" | 33.75 | | $ 116,843.45 | $ 101,603.00 | | 0.6 | | | 4.962222222 | | | | 20.3 | | 270 |
| Mulch finisher 38 ft 3" | 38.25 | | $ 134,188.90 | $ 116,686.00 | | 0.6 | | | 4.960784314 | | | | 23 | | 310 |
| Mulch finisher 44 ft 3" | 44.25 | | $ 158,875.95 | $ 138,153.00 | | 0.6 | | | 4.959322034 | | | | 26.6 | | 370 |
| Mulch finisher 50 ft 3" | 50.25 | | $ 177,277.10 | $ 154,154.00 | | 0.5 | | | 4.958208955 | | | | 30.2 | | 370 |
| Mulch finisher 56 ft 3" | 56.25 | | $ 189,562.55 | $ 164,837.00 | | 0.5 | | | 4.957333333 | | | | 33.8 | | 420 |
| Field Cultivator | | | | | | | | | | | | | | | |
| Field Cultivator/ Seedbed Conditioner 20 ft | 20 | | | | | | 0.7 | 7 | | | 0.85 | 14.4 | | | |
| Field Cultivator 23 Ft | 23 | $ 37,000.00 | | | 0.31 | | 0.7 | | | 5.95076087 | | | | 16.59 | 105 HP MFWD |
| Field Cultivator/ Seedbed Conditioner 24 ft | 24 | | | | | | 0.7 | 7 | | | 0.85 | 17.3 | | | |
| Field cultivator 29 ft 6 in | 29.5 | | $ 67,358.95 | $ 58,573.00 | | 0.4 | 0.7 | 7 | 5.397457627 | | | | 19.3 | | 155 |
| Field cultivator 31 ft. 6 in, | 31.5 | | $ 68,221.45 | $ 59,323.00 | | 0.5 | 0.7 | | 5.395238095 | | | | 20.6 | | 225 |
| Field cultivator 35 ft. 6 in. | 35.5 | | $ 71,086.10 | $ 61,814.00 | | 0.4 | 0.7 | | 5.391549296 | | | | 23.2 | | 240 |
| Field Cultivator/ Seedbed Conditioner 36 ft | 36 | | | | | | 0.7 | 7 | | | 0.83 | 25.4 | | | |
| Field cultivator 40 ft. 6 in. | 40.5 | | $ 99,154.15 | $ 86,221.00 | | 0.4 | 0.7 | | 5.398148148 | | | | 26.5 | | 270 |

**Appendix A Table 2 (continued):** Implement Price and Performance Data (Manitoba, 2020, Lattz and Schnitkey, 2019, and Lazarus, 2012)

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field cultivator 44 ft. 6 in. | 44.5 | | $ 103,270.00 | $ 89,800.00 | | 0.4 | 0.7 | | 5.39494382 | | | | 29.1 | | | 270 |
| Field Cultivator/ Seedbed Conditioner 45 ft | 45 | | | | | | 0.7 | 7 | | | 0.8 | 30.5 | | | | |
| Field Cultivator 47 Ft | 47 | $ 69,000.00 | | | 0.31 | | 0.7 | | | 5.950531915 | | | | 33.9 | 260 HP MFWD | |
| Field cultivator 48 ft. 6 in. | 48.5 | | $ 109,827.30 | $ 95,502.00 | | 0.4 | 0.7 | | 5.460309278 | | | | 32.1 | | | 290 |
| Field Cultivator/ Seedbed Conditioner 50 ft | 50 | | | | | | 0.7 | 7 | | | 0.8 | 33.9 | | | | |
| Field Cultivator 52 ft. 6 in. | 52.5 | | $ 113,720.05 | $ 98,887.00 | | 0.4 | 0.7 | | 5.452857143 | | | | 34.7 | | | 310 |
| Field Cultivator 56 ft. 6 in. | 56.5 | | $ 119,624.15 | $ 104,021.00 | | 0.4 | 0.7 | | 5.461061947 | | | | 37.4 | | | 310 |
| Field Cultivator 60 Ft | 60 | $ 90,000.00 | | | 0.31 | | 0.7 | | | 5.949625 | | | | 43.27 | 310 HP 4WD | |
| Field Cultivator 60 ft. 6 in. | 60.5 | | $ 121,433.10 | $ 105,594.00 | | 0.4 | 0.7 | | 5.454545455 | | | | 40 | | | 370 |
| Field Cultivator 64 ft. 6 in. | 64.5 | | $ 123,428.35 | $ 107,329.00 | | 0.4 | 0.7 | | 5.461627907 | | | | 42.7 | | | 420 |
| Field Cultivator/ Seedbed Conditioner 65 ft | 65 | | | | | | 0.7 | 7 | | | 0.78 | 43 | | | | |
| Tandem Disk | | | | | | | | 5-6mph | | | | | | | | |
| Tandem Disk 21 Ft Fold | 21 | $ 60,000.00 | | | 0.74 | | 0.65 | | | 4.800714286 | | | | 12.22 | 160 HP MFWD | |
| Tandem Disk 23 ft. 7 in. | 23.58 | | $ 69,340.40 | $ 60,296.00 | | 0.4 | 0.65 | | 4.968193384 | | | | 14.2 | | | 140 |
| Tandem Disk 26 ft. 5 in. | 26.42 | | $ 76,810.80 | $ 66,792.00 | | 0.5 | 0.65 | | 4.964988645 | | | | 15.9 | | | 175 |
| Tandem Disk 29 ft. 3 in. | 29.25 | | $ 82,505.60 | $ 71,744.00 | | 0.5 | 0.65 | | 4.992307692 | | | | 17.7 | | | 225 |
| Tandem Disk 33 ft. 7 in. | 33.58 | | $ 94,257.45 | $ 81,963.00 | | 0.5 | 0.65 | | 4.987343657 | | | | 20.3 | | | 240 |
| Tandem Disk 30 Ft Fold | 30 | $ 84,000.00 | | | 0.74 | | 0.65 | | | 4.79875 | | | | 17.45 | 360 HP 4WD | |
| Planting | | | | | | | | | | | | | | | | |
| Broadcast seeding | | | | | | | | | | | | | | | | |
| Broadcast Seeding 20 ft | 20 | | $ 3,264.85 | $ 2,839.00 | | 0.5 | 0.15 | | 3.3 | | | | 8 | | | 85 |
| Conventional planter | | | | | | | | 5.5 mph | | | | | | | | |
| Planter, row-crop 6 row | 15 | $ 35,000.00 | $ 44,586.65 | $ 38,771.00 | 0.4 | 0.5 | 0.4 | 5.5 | 4.18 | 3.85 | 0.65 | 6.5 | 7.6 | 7 | 60 HP | 95 |
| Planter, row-crop 8 row | 20 | $ 49,000.00 | $ 62,817.60 | $ 54,624.00 | 0.4 | 0.5 | 0.4 | 5.5 | 4.19137931 | 3.83387931 | 0.65 | 8.7 | 10.2 | 9.33 | 75 HP | 110 |
| Planter, row-crop 12 row | 30 | $ 108,000.00 | $ 121,759.70 | $ 105,878.00 | 0.4 | 0.4 | 0.4 | 5.5 | 4.2075 | 3.85 | 0.65 | 13 | 15.3 | 14 | 105 HP MFWI | 140 |
| Planter, row-crop 16 row | 40 | $ 159,000.00 | $ 154,677.30 | $ 134,502.00 | 0.4 | 0.3 | 0.4 | 5.5 | 4.2075 | 3.8506875 | 0.63 | 16.8 | 20.4 | 18.67 | 200 HP MFWI | 155 |
| Planter, row-crop 24 row | 60 | $ 249,000.00 | $ 236,985.10 | $ 206,074.00 | 0.4 | 0.3 | 0.4 | 5.5 | 4.19375 | 3.85 | 0.6 | 24 | 30.5 | 28 | 310 HP 4WD | 190 |
| Planter, row-crop 36 row | 90 | | $ 420,638.95 | $ 365,773.00 | | 0.3 | 0.4 | 5.5 | 3.730833333 | | 0.58 | 34.8 | 40.7 | | | 225 |
| Planter, row-crop 48 row | 120 | | $ 453,439.25 | $ 394,295.00 | | 0.3 | 0.4 | 5.5 | 3.14875 | | 0.55 | 44 | 45.8 | | | 270 |
| Split-row planter (soybean acres only)[2] | | | | | | | | | | | | | | | | |
| Split-row planter 12-row split | | | $ 53,668.20 | $ 46,668.00 | | 0.4 | | | | | | | 15.3 | | | 155 |
| Split-row planter 6-row split | | | $ 68,528.50 | $ 59,590.00 | | 0.4 | | | | | | | 20.4 | | | 175 |
| No-till planter (30" rows) | | | | | | | | 5-6 mph | | | | | | | | |
| No-till planter 8-row | 20 | | $ 72,795.00 | $ 63,300.00 | | 0.5 | 0.45 | 6 | 4.2075 | | | | 10.2 | | | 110 |
| No-till planter 12-row | 30 | | $ 136,718.90 | $ 118,886.00 | | 0.4 | 0.45 | 6 | 4.2075 | | | | 15.3 | | | 155 |
| No-till planter 16-row | 40 | | $ 172,930.10 | $ 150,374.00 | | 0.5 | 0.45 | 5 | 4.2075 | | | | 20.4 | | | 225 |
| No-till planter 24-row | 60 | | $ 264,364.30 | $ 229,882.00 | | 0.3 | 0.45 | 5 | 4.19375 | | | | 30.5 | | | 240 |
| Grain Drill | | | | | | | | | | | | | | | | |
| Grain or soybean drill 10 ft | 10 | | | | | | 0.15 | 6 | | | 0.7 | 5.1 | | | | |
| Grain Drill 13 ft | 13 | | $ 21,463.60 | $ 18,664.00 | | 0.7 | 0.15 | 6 | 3.871153846 | | | | 6.1 | | | 95 |
| Grain or soybean drill 15 ft | 15 | | | | | | 0.15 | 6 | | | 0.7 | 7.6 | | | | |
| Grain or soybean drill 20 ft | 20 | | | | | | 0.15 | 6 | | | 0.7 | 10.2 | | | | |
| Grain or soybean drill 25 ft | 25 | | $ 53,409.45 | $ 46,443.00 | | 0.5 | 0.15 | 6 | 3.849677419 | | 0.68 | 12.4 | 11.7 | | | 140 |
| Grain or soybean drill 30 ft | 30 | | $ 67,881.05 | $ 59,027.00 | | 0.5 | 0.15 | 6 | 3.859459459 | | 0.68 | 14.8 | 14 | | | 175 |
| Grain Drill 35 ft. | 35 | | $ 80,868.00 | $ 70,320.00 | | 0.6 | 0.15 | 6 | 3.842142857 | | | | 16.3 | | | 225 |
| Presswheel Drill 16 Ft | 16 | $ 23,000.00 | | | 0.61 | | 0.15 | | | 3.50109375 | | | | 6.79 | 105 HP MFWD | |
| Presswheel Drill 20 Ft | 20 | $ 28,000.00 | | | 0.61 | | 0.15 | | | 3.498 | | | | 8.48 | 130 HP MFWD | |
| Presswheel Drill 25 Ft | 25 | $ 48,000.00 | | | 0.61 | | 0.15 | | | 3.5013 | | | | 10.61 | 130 HP MFWD | |
| Presswheel Drill 30 Ft | 30 | $ 61,000.00 | | | 0.61 | | 0.15 | | | 3.50075 | | | | 12.73 | 160 HP MFWD | |
| No-till drill | | | | | | | | | | | | | | | | |

**Appendix A Table 2 (continued):** Implement Price and Performance Data (Manitoba, 2020, Lattz and Schnitkey, 2019, and Lazarus, 2012)

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No-till drill 10 ft | 10 | | $ 52,187.00 | $ 45,380.00 | | 1 | | 5-6 mph | 3.8775 | | | | 4.7 | | | 110 |
| No-till drill 15 ft | 15 | $ 56,000.00 | $ 60,064.50 | $ 52,230.00 | 0.9 | 0.9 | | | 3.85 | 3.498 | | | 7 | 6.36 | 130 HP MFWI | 140 |
| No-till drill 20 ft. | 20 | | $ 88,619.00 | $ 77,060.00 | | 0.8 | | | 3.83625 | | | | 9.3 | | | 175 |
| Air seeder | | | | | | | | | | | | | | | | |
| Air drill 25 ft | 25 | | | | | | 0.7 | 6 | | | 0.7 | 12.7 | | | | |
| Air seeder 28 ft | 28 | | $ 77,853.85 | $ 67,699.00 | | 0.9 | 0.7 | 6 | 4.213392857 | | | | 14.3 | | | 290 |
| Air drill 30 ft | 30 | | | | | | 0.7 | 6 | | | 0.7 | 15.3 | | | | |
| Air seeder 36 ft. | 36 | | $ 105,681.55 | $ 91,897.00 | | 0.7 | 0.7 | | 4.19375 | | | | 18.3 | | | 290 |
| Air drill 40 ft | 40 | | | | | | 0.7 | 6 | | | 0.68 | 19.8 | | | | |
| Air seeder 44 ft. | 44 | | $ 131,152.90 | $ 114,046.00 | | 0.6 | 0.7 | | 4.2 | | | | 22.4 | | | 310 |
| Air drill 50 ft | 50 | | | | | | 0.7 | 6 | | | 0.68 | 24.7 | | | | |
| Air Seeder Drill w/Cart 52 Ft | 52 | $ 233,000.00 | | | 0.52 | | 0.7 | | | 3.499903846 | | | | 22.06 | 260 HP MFWD | |
| Air drill 60 ft | 60 | | | | | | 0.7 | 6 | | | 0.68 | 29.7 | | | | |
| Crop Maintenance | | | | | | | | | | | | | | | | |
| Rotary hoe | | | | | | | | | | | | | | | | |
| Rotary hoe 30 ft | 30 | | $ 13,800.00 | $ 12,000.00 | | 0.2 | 0.2 | | 8.305 | | | | 30.2 | | | 140 |
| Rotary hoe 40 ft. | 40 | | $ 26,450.00 | $ 23,000.00 | | 0.3 | 0.2 | | 8.29125 | | | | 40.2 | | | 225 |
| Row-crop cultivator (30" rows) | | | | | | | | | | | | | | | | |
| Row-crop cultivator 8-row | 20 | | $ 13,800.00 | $ 12,000.00 | | 0.7 | 0.4 | | 3.75375 | | | | 9.1 | | | 140 |
| Row-crop cultivator 12-row | 30 | $ 38,000.00 | $ 29,900.00 | $ 26,000.00 | 0.46 | 0.5 | 0.4 | | 3.74 | 4.24875 | | | 13.6 | 15.45 | 160 HP MFWI | 155 |
| Row-crop cultivator 16-row | 40 | | $ 40,250.00 | $ 35,000.00 | | 0.5 | 0.4 | | 3.733125 | | | | 18.1 | | | 225 |
| Self-propelled sprayer (High-crop ready) | | | | | | | | 12mph | | | | | | | | |
| Self-propelled sprayer 80 ft boom | 80 | | $ 288,103.75 | $ 250,525.00 | | 0.1 | | 12 | 6.6515625 | | | | 64.5 | | | 85 |
| Self-propelled sprayer 90 ft boom | 90 | | $ 405,476.20 | $ 352,588.00 | | 0.04 | | 12 | 6.645833333 | | | | 72.5 | | | 85 |
| Self-propelled sprayer 100 ft boom | 100 | | $ 419,769.55 | $ 365,017.00 | | 0.04 | | 12 | 6.6495 | | | | 80.6 | | | 85 |
| Self-propelled sprayer | | | | | | | | | | | | | | | | |
| Sprayer– self-propelled 90 ft | 90 | | | | | | | 12 | | | 0.6 | 78.5 | | | | |
| Sprayer– self-propelled 100 ft | 100 | | | | | | | 12 | | | 0.6 | 87.3 | | | | |
| Sprayer– self-propelled 120 ft | 120 | | $ 450,453.85 | $ 391,699.00 | | 0.04 | | 12 | 6.650513834 | | 0.58 | 101.2 | 96.7 | | | 85 |
| Boom Sprayer, Self-Propelled 90 Ft | 90 | $ 276,000.00 | | | 0.07 | | | 12 | | | | | | | None | |
| Field Sprayer | | | | | | | | | | | | | | | | |
| Sprayer – pull type 30 ft | 30 | | | | | | 0.1 | 7 | | | 0.65 | 16.5 | | | | |
| Sprayer – pull type 60 ft | 60 | | | | | | 0.1 | 7 | | | 0.63 | 32.1 | | | | |
| Sprayer – pull type 80 ft | 80 | | | | | | 0.1 | 7 | | | 0.63 | 42.8 | | | | |
| Sprayer – pull type 90 ft | 90 | | $ 56,448.90 | $ 49,086.00 | | 0.1 | 0.1 | 12 | 4.519111111 | | | | 49.6 | | | 95 |
| Boom Sprayer, Pull-Type 90 Ft | 90 | $ 47,000.00 | | | 0.12 | | 0.1 | 12 | | 4.224916667 | | | | 46.09 | 130 HP MFWD | |
| Anhydrous ammonia applicator | | | | | | | | 5-6 mph | | | | | | | | |
| Anhydrous ammonia applicator 27 ft. 6 in. | 27.5 | | $ 86,458.15 | $ 75,181.00 | | 0.5 | 0.55 | | 3.99 | | | | 13.3 | | | 140 |
| Anhydrous Ammonia Applicator 15 Knife | 37 | | | | | | 0.55 | 6 | | | 0.65 | 17.7 | | | | |
| Anhydrous ammonia applicator 37 ft. 6 in. | 37.5 | | $ 108,560.00 | $ 94,400.00 | | 0.6 | 0.55 | | 4.004 | | | | 18.2 | | | 240 |
| Anhydrous Ammonia Applicator 17 Knife | 43 | | | | | | 0.55 | 6 | | | 0.63 | 19.5 | | | | |
| Anhydrous ammonia applicator 47 ft. 6 in. | 47.5 | | $ 126,493.10 | $ 109,994.00 | | 0.5 | 0.55 | | 3.994736842 | | | | 23 | | | 290 |
| Anhydrous ammonia applicator 52 ft. 6 in. | 52.5 | | $ 131,936.05 | $ 114,727.00 | | 0.6 | 0.55 | | 4.007142857 | | | | 25.5 | | | 370 |
| Anhydrous Ammonia Applicator 23 Knife | 58 | | | | | | 0.55 | 5 | | | 0.63 | 22 | | | | |

**Appendix A Table 2 (continued):** Implement Price and Performance Data (Manitoba, 2020, Lattz and Schnitkey, 2019, and Lazarus, 2012)

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Anhydrous ammonia applicator 62 ft. 6 in. | 62.5 | | | $ 146,013.20 | $ 126,968.00 | | | 0.7 | 0.55 | | 3.9996 | | | | | 30.3 | | | 470 |
| Liquid Fertilizer Applicator | | | | | | | | | | 6-12 mph | | | | | | | | | |
| Fertilizer Spreader 40 ft | 40 | | | $ 66,598.80 | $ 57,912.00 | | | 0.3 | 0.15 | 6 | 6.382352941 | | 0.7 | | 20.4 | 31 | | | 190 |
| Fertilizer Spreader 60 ft | 60 | | | $ 82,959.85 | $ 72,139.00 | | | 0.3 | 0.15 | 6 | 6.387878788 | | 0.68 | | 29.7 | 46.5 | | | 270 |
| Fertilizer Spreader 60 ft | 60 | | | | | | | | 0.15 | 12 | | | 0.68 | | 59.3 | | | | |
| Fertilizer Spreader 80 ft | 80 | | | | | | | | 0.15 | 6 | | | 0.68 | | 39.6 | | | | |
| Fertilizer Spreader 80 ft | 80 | | | | | | | | 0.15 | 12 | | | 0.68 | | 79.1 | | | | |
| Manure Spreader Box or Liquid 15 ft | 15 | | | | | | | | 0.15 | 5 | | | 0.63 | | 5.7 | | | | |
| Manure Spreader Box or Liquid 20 ft | 20 | | | | | | | | 0.15 | 6 | | | 0.63 | | 9.2 | | | | |
| Manure Spreader Box or Liquid 30 ft | 30 | | | | | | | | 0.15 | 6 | | | 0.6 | | 13.1 | | | | |
| Manure Spreader Liquid Inject 36 ft | 36 | | | | | | | | 0.15 | 5 | | | 0.6 | | 13.1 | | | | |
| Manure Spreader Liquid Inject 45 ft | 45 | | | | | | | | 0.15 | 5 | | | 0.6 | | 16.4 | | | | |
| Field and ditch mowing | | | | | | | | | | 7mph | | | | | | | | | |
| Field and ditch mowing 15 ft | 15 | | | $ 24,131.60 | $ 20,984.00 | | | 1 | | | 3.19 | | | | | 5.8 | | | 140 |
| Field and ditch mowing 20 ft. | 20 | | | $ 31,439.85 | $ 27,339.00 | | | 0.8 | | | 3.2175 | | | | | 7.8 | | | 140 |
| Stalk Shredder | | | | | | | | | | | | | | | | | | | |
| Stalk Shredder 20 Ft | 20 | | $ 30,000.00 | | | | 0.74 | | | | | 3.201 | | | | | 7.76 | 130 HP MFWD | |
| Harvest | | | | | | | | | | | | | | | | | | | |
| Mower conditioner, rotary 8 ft | 8 | | | | | | | | 0.55 | 7 | | | 0.83 | | 5.6 | | | | |
| Mower conditioner, rotary 10 ft | 10 | | | | | | | | 0.55 | 7 | | | 0.83 | | 7 | | | | |
| Rotary Mower/Conditioner 12 Ft | 12 | | $ 37,000.00 | | | | 0.38 | | 0.55 | 7 | | 6.001875 | | | | | 8.73 | 75 HP | |
| Mower conditioner, rotary 13 ft | 13 | | | | | | | | 0.55 | 7 | | | 0.8 | | 8.8 | | | | |
| Mower conditioner, rotary 14 ft | 14 | | | | | | | | 0.55 | 7 | | | 0.8 | | 9.5 | | | | |
| Mower conditioner, rotary 16 ft | 16 | | | | | | | | 0.55 | 7 | | | 0.78 | | 10.6 | | | | |
| Mower conditioner, rotary 19 ft | 19 | | | | | | | | 0.55 | 7 | | | 0.78 | | 12.6 | | | | |
| SP Disc Mower Conditioner 13-19 FT | | $ 201,000.00 | | | | 9.510192 | | | 0.45 | | | | | 12 | | | | | |
| SP Disc Mower Conditioner 30 FT | | $ 500,000.00 | | | | 16.907008 | | | 0.45 | | | | | 23 | | | | | |
| SP Sickle Mower Conditioner 14-18 FT | | $ 189,000.00 | | | | 8.453504 | | | 0.45 | | | | | 9 | | | | | |
| Rake 16 ft | 16 | | | | | | | | 0.25 | 7 | | | 0.8 | | 10.9 | | | | |
| Rake 20 ft | 20 | | | | | | | | 0.25 | 7 | | | 0.8 | | 13.6 | | | | |
| Rake 25 ft | 25 | | | | | | | | 0.25 | 7 | | | 0.78 | | 16.5 | | | | |
| Rake 30 Ft | 30 | | $ 23,000.00 | | | | 0.07 | | 0.25 | 7 | | 7.1995 | | | | | 26.18 | 40 HP | |
| Grain Swather, Self-Propelled 25 Ft | 25 | | $ 186,000.00 | | | | 0.32 | | | | | 3.9996 | | | | | 12.12 | None | |
| Small Square Baler w/accumulator | | | | | | | | | 0.4 | | | | | | | | | | |
| Small Square Baler w/bale thrower | | | | | | | | | 0.4 | | | | | | | | | | |
| Small Square Bales Load Haule and Stack 1 mile | | | | | | | | | 0.4 | | | | | | | | | | |
| Hay Baler PTO Twine 12 Ft | 12 | | $ 33,000.00 | | | | 0.4 | | 0.4 | | | 2.9975 | | | | | 4.36 | 40 HP | |
| Large Round Baler | | $ 27,000.00 | | | | | | | 0.4 | | | | | 17 | | | | | |
| Large Round Bale move in field | | | | | | | | | 0.4 | | | | | | | | | | |
| Large Round Bale haul/ store 1 mile away | | | | | | | | | 0.4 | | | | | | | | | | |
| Round Baler 4x5 , 20 Ft | 20 | $ 42,000.00 | $ 35,000.00 | | | | 0.35 | | 0.4 | | | 3.898125 | | 15 | | | 9.45 | 75 HP | |
| Round Baler 5x6 , 20 Ft | 20 | $ 50,000.00 | $ 60,000.00 | | | | 0.35 | | 0.4 | | | 3.898125 | | 12 | | | 9.45 | 75 HP | |
| Round Baler w/Bale Wrap 5x6 , 20 Ft | 20 | | $ 78,000.00 | | | | 0.35 | | 0.4 | | | 3.898125 | | | | | 9.45 | 75 HP | |

## **Appendix A Table 2 (continued):** Implement Price and Performance Data (Manitoba, 2020, Lattz and Schnitkey, 2019, and Lazarus, 2012)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Large Rectangular Baler | | $ | 150,000.00 | | | 0.4 | | | | 40 | | | |
| Large Rectangular Baler 3x3 , 20 Ft | 20 | $ | 180,000.00 | $ 121,000.00 | 0.49 | 0.4 | | 4.8015 | | 40 | | 11.64 | 130 HP MFWD |
| Large Rectangular Baler 4x3 , 20 Ft | 20 | $ | 225,000.00 | $ 144,000.00 | 0.49 | 0.4 | | 4.8015 | | 40 | | 11.64 | 130 HP MFWD |
| Forage Harvester, Pull-Type w/Corn Head 3 Row, 7.5 Ft | 7.5 | | | $ 70,000.00 | 3.4 | 0.8 | | 2.277 | | | | 2.07 | 160 HP MFWD |
| Forage Harvester, Pull-Type w/Pickup Head 12 Ft | 12 | | | $ 62,000.00 | 1.4 | 0.8 | | 2.275625 | | | | 3.31 | 105 HP MFWD |
| Forage harvester pull-type, 150 HP | | | | | | 0.8 | | | | | | | |
| Forage harvester pull-type, 175 HP | | | | | | 0.8 | | | | | | | |
| Forage harvester pull-type, 200 HP | | | | | | 0.8 | | | | | | | |
| Forage harvester pull-type, 250+ HP | | | | | | 0.8 | | | | | | | |
| Forage Harvester, Self-Prop Corn Head 6 Row, 15 Ft | 15 | | | $ 82,000.00 | 2.58 | 1.7 | | 2.7995 | | | | 5.09 | 625 HP SP Forage Harvester Base |
| Forage Harvester, Self-Prop Corn Head 8 Row, 20 Ft | 20 | | | $ 109,000.00 | 2.58 | 1.7 | | 2.800875 | | | | 6.79 | 625 HP SP Forage Harvester Base |
| Forage Harvester self-propelled, 2 row | 5 | | | | | 0.85 | | | | | | | |
| Self-propelled forage harvester 3 row | 5 | | | | | 0.85 | 3.7 | | 0.73 | | 1.6 | | |
| Self-propelled forage harvester 3 row | 8 | | | | | 0.85 | 3.7 | | 0.71 | | 2.4 | | |
| Self-propelled forage harvester 4 row | 10 | | | | | 0.85 | 3.7 | | 0.7 | | 3.2 | | |
| Self-propelled forage harvester 6 row | 15 | | | | | 0.85 | 3.7 | | 0.7 | | 4.7 | | |
| Forage Harvester, Self-Prop Pickup Head 12 Ft | 12 | | | $ 13,000.00 | 2.36 | 0.85 | | 2.798125 | | | | 4.07 | 400 HP SP Forage Harvester Base |
| Forage Harvester, Self-Prop Pickup Head (2X windrows) 24 Ft | 24 | | | $ 26,000.00 | 1.84 | 0.85 | | 2.8015625 | | | | 8.15 | 625 HP SP Forage Harvester Base |
| Self-propelled windrower 15 ft | 15 | | | | | 0.45 | 6.5 | | 0.83 | | 9.8 | | |
| Self-propelled windrower 18 ft | 18 | | | | | 0.45 | 6.5 | | 0.8 | | 11.3 | | |
| Self-propelled windrower 21 ft | 21 | | | | | 0.45 | 6.5 | | 0.8 | | 13.2 | | |
| Self-propelled windrower 25 ft | 25 | | | | | 0.45 | 6.5 | | 0.78 | | 15.4 | | |
| Self-propelled windrower 30 ft | 30 | | | | | 0.45 | 6.5 | | 0.78 | | 18.4 | | |
| Combine, soybeans and small grains 15 ft | 15 | | | | | 1 | 3.8 | | 0.73 | | 5 | | |
| Combine, soybeans and small grains 17.5 ft | 15 | | | | | 1 | 3.8 | | 0.73 | | 5.2 | | |
| Combine Flex Platform 20 Ft | 20 | $ | 41,000.00 | $ 29,000.00 | 2.04 | 1 | 0 | 2.45025 | 3.8 | | 0.7 | 5.94 | 275 HP Combine |
| Combine, soybeans and small grains 22.5ft | 23 | | | | | 1 | 3.8 | | 0.7 | | 7.3 | | |
| Combine Flex Platform 25 Ft | 25 | $ | 45,000.00 | $ 32,000.00 | 2.04 | 1 | 0 | 2.4486 | 3.8 | | 0.7 | 7.42 | 375 HP Combine |
| Combine Flex Platform 30 Ft | 30 | $ | 50,000.00 | $ 39,000.00 | 2.04 | 1 | 0 | 2.45025 | 3.8 | | 0.68 | 8.91 | 375 HP Combine |
| Combine, soybeans and small grains 35 ft | 35 | | | | | 1 | 4.5 | | 0.75 | | 14.3 | | |
| Combine, soybeans and small grains 36 ft | 36 | | | | | 1 | 3.8 | | 0.68 | | 11.3 | | |
| Combine, soybeans and small grains 40ft | 40 | | | | | 1 | 4.5 | | 0.75 | | 16.4 | | |
| Combine, soybeans and small grains 45ft | 45 | | | | | 1 | 4.5 | | 0.75 | | 18.4 | | |
| Combine, corn 4 row | 10 | | | | | 1.45 | 3.8 | | 0.73 | | 3.4 | | |
| Combine, corn 6 row | 15 | $ | 65,000.00 | $ 47,000.00 | 2 | 1.45 | 3.8 | 2.823932 | 0.73 | | 5 | 5.09 | 275 HP Combine |
| Combine, corn 8 row | 20 | $ | 80,000.00 | $ 61,000.00 | 2 | 1.45 | 3.8 | 2.82209375 | 0.7 | | 6.4 | 6.79 | 275 HP Combine |

**Appendix A Table 2 (continued):** Implement Price and Performance Data (Manitoba, 2020, Lattz and Schnitkey, 2019, and Lazarus, 2012)

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Combine Chopping Corn Hd 8 Row-30, 20 Ft | 20 | | $ 82,000.00 | | 1.9 | 1.45 | | 2.800875 | | | | 6.79 | 275 HP Combine |
| Combine, corn 12 row | 30 | $ 125,000.00 | $ 94,000.00 | | 2 | 1.45 | 3.8 | 2.798417021 | 0.68 | | 9.4 | 10.18 | 375 HP Combine |
| Combine Corn Hd 12 Row-22, 22 Ft | 22 | | $ 93,000.00 | | 2 | 1.45 | | 2.80125 | | | | 7.47 | 375 HP Combine |
| Combine, corn 4-38 row | 13 | | | | | 1.45 | 3.8 | | 0.73 | | 4.3 | | |
| Combine, corn 6-38 row | 19 | | | | | 1.45 | 3.8 | | 0.73 | | 6.4 | | |
| Combine, corn 8-38 row | 25 | | | | | 1.45 | 3.8 | | 0.7 | | 8.2 | | |
| Combine Chopping Corn Hd 12 Row- 30, 30 Ft | 30 | | $ 124,000.00 | | 1.9 | 1.45 | | 2.7995 | | | | 10.18 | 440 HP Combine |
| Combine Chopping Corn Hd 12 Row- 22, 22 Ft | 22 | | $ 123,000.00 | | 1.9 | 1.45 | | 2.80125 | | | | 7.47 | 440 HP Combine |
| Combine Belt Pickup Hd 23 Ft | 23 | | $ 39,000.00 | | 1.55 | 1.45 | | 2.801413043 | | | | 7.81 | 275 HP Combine |
| Grain Cart 30 Ft | 30 | | $ 118,000.00 | | 1.44 | | | 1.88925 | | | | 6.87 | 225 HP MFWD |
| SP Swather Draper Header 18-22 FT | | $ 220,000.00 | | 5.811784 | | 0.85 | | | | 11 | | | |
| SP Swather Draper Header 25 FT | | $ 240,000.00 | | 5.811784 | | 0.85 | | | | 13 | | | |
| SP Swather Draper Header 30 FT | | $ 270,000.00 | | 8.453504 | | 0.85 | | | | 16 | | | |
| SP Swather Draper Header 35-40 FT | | $ 290,000.00 | | 9.510192 | | 0.85 | | | | 20 | | | |
| Grain Cart Small 500-1,000 bu | | $ 55,000.00 | | | | | | | | | | | |
| Grain Cart Medium 1,050-1,600 bu | | $ 125,000.00 | | | | | | | | | | | |
| Grain Cart Large 2,000 bu | | $ 185,000.00 | | | | | | | | | | | |
| Powered Auger 8” 30-39 FT, 20 hp engine | | $ 17,000.00 | | | | | | | | | | | |
| Powered Auger 8” 40-49 FT, 20 hp engine | | $ 17,000.00 | | | | | | | | | | | |
| Powered Auger 8” 50-59 FT, 25 hp engine | | $ 17,000.00 | | | | | | | | | | | |
| Powered Auger 10” 40-49 FT, 35 hp engine | | $ 22,000.00 | | | | | | | | | | | |
| Powered Auger 10” 50-59 FT, 38 hp engine | | $ 23,000.00 | | | | | | | | | | | |
| Powered Auger 12-13” 39-40 FT, 38-50 hp diesel engine | | $ 31,000.00 | | | | | | | | | | | |
| Grain Auger PTO 8” 30-69 FT | | $ 6,500.00 | | | | | | | | 2,700-3,200 bu/hr | | | |
| Grain Auger PTO 10” 40-89 FT | | $ 15,000.00 | | | | | | | | 5,400 bu/hr | | | |
| Grain Auger PTO 12” 70+ FT | | $ 33,000.00 | | | | | | | | 8,400 bu/hr | | | |
| Grain Auger PTO 13” 70-120 FT | | $ 37,000.00 | | | | | | | | 9,700 bu/hr | | | |
| Grain Auger PTO 16” 80+ FT | | $ 60,000.00 | | | | | | | | 21,000 bu/hr | | | |

## APPENDIX B

## Excel Model Visual Basic Code

```
Sub DataTransfer()

Application.ScreenUpdating = False

Dim wsMDL As Worksheet

Dim wsDB As Worksheet

Dim wsRPT As Worksheet

Dim LRRPT As Long

Dim LRDB As Long

Dim Rpt As Range

Dim Md As Range

Dim TotCost As Range

Dim TotCost2 As Range

Dim TotCost3 As Range

Dim TotCost4 As Range


Set wsMDL = Worksheets("Model")

Set wsDB = Worksheets("ModelDataBase")
```

```
Set wsRPT = Worksheets("CostsReport")

Set Rpt = wsMDL.Range("L7:R46")

Set Md = wsMDL.Range("A7:F73")

Set TotCost1 = wsMDL.Range("M17:R21")

Set TotCost2 = wsMDL.Range("M24:R29")

Set TotCost3 = wsMDL.Range("M32:R37")

Set TotCost4 = wsMDL.Range("M40:R45")


LRRPT = wsRPT.Cells(wsRPT.Rows.Count, "A").End(xlUp).Offset(1).Row

LRDB = wsDB.Cells(wsDB.Rows.Count, "A").End(xlUp).Offset(1).Row


Rpt.Copy

With wsRPT.Range("A" & LRRPT + 5)

   .PasteSpecial xlValues

   .PasteSpecial xlFormats


End With

Md.Copy

With wsDB.Range("A" & LRDB + 4)

   .PasteSpecial xlValues

   .PasteSpecial xlFormats

End With

TotCost1.Copy

With wsRPT.Range("J9:O13")
```

```
   .PasteSpecial xlPasteValuesAndNumberFormats, xlPasteSpecialOperationAdd
End With
TotCost2.Copy
With wsRPT.Range("J16:O21")
   .PasteSpecial xlPasteValuesAndNumberFormats, xlPasteSpecialOperationAdd
   End With
TotCost3.Copy
With wsRPT.Range("J24:O29")
   .PasteSpecial xlPasteValuesAndNumberFormats, xlPasteSpecialOperationAdd
End With
TotCost4.Copy
With wsRPT.Range("J32:O37")
   .PasteSpecial xlPasteValuesAndNumberFormats, xlPasteSpecialOperationAdd
End With
wsRPT.Cells.EntireColumn.AutoFit
wsDB.Cells.EntireColumn.AutoFit
'wsMDL.Range("B39:B41,B44,B46,B48, B50,B54, B56, B65, B67, B69, C7:C13,
B14:B16, B19, B21, B23, B27, C50,
B29").SpecialCells(xlCellTypeConstants).ClearContents
Application.CutCopyMode = False
Application.ScreenUpdating = True
End Sub


Sub Reset()
```

```
Application.ScreenUpdating = False
Dim wsMDL As Worksheet
Set wsMDL = Worksheets("Model")
wsMDL.Range("B39:B41,B44,B46,B48, B50,B54, B56, B65, B67, B69,C23, C7:C13, B14:B16, B19, B21, B23, B27, C50, B29, D39").Select
Selection.SpecialCells(xlCellTypeConstants, 23).ClearContents
Application.ScreenUpdating = True
End Sub


Sub ClearDataBase()
Application.ScreenUpdating = False
Dim wsDB As Worksheet
Dim wsRPT As Worksheet
Dim Rpt As Range
Dim Md As Range
Set wsMDL = Worksheets("Model")


Set wsDB = Worksheets("ModelDataBase")
Set wsRPT = Worksheets("CostsReport")
wsRPT.Range("A:H").Clear
wsRPT.Range("J9:O13").ClearContents
wsRPT.Range("J16:O21").ClearContents
wsRPT.Range("J24:O29").ClearContents
wsRPT.Range("J32:O37").ClearContents
```

```
wsDB.Cells.Clear

Application.CutCopyMode = False

Application.ScreenUpdating = True


End Sub
```

# VITA

Guy Wyatt Buser

Candidate for the Degree of

Master of Science

Thesis: CONCEPTUAL DESIGN FOR SWITCHGRASS PRODUCTION SIMULATION IN A BIOMASS SUPPLY CHAIN USING GLADIS 2.0

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Biographical:

Education:

Completed the requirements for the Master of Science in Agricultural Economics at Oklahoma State University, Stillwater, Oklahoma in December, 2020.

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Experience:

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