McGill University
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BREE 495 – Engineering Design 3

Mechanization of seeder for smallholder farmers in Rwanda

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Abstract

A mechanized seeder for Rwandan farmers is presented with the goal of providing sufficient means for farmers to seed effectively and efficiently their crops during the growing season of Rwanda. The system was designed as an alternative to the current methods used which consist often of manual seeding. The newly proposed method of seeding aims to reduce farm losses by increasing efficiency and precision. Soil mechanics, agronomic requirements for seed establishment, and many more factors were taken into consideration. The proposed design is a modification of an existing seeder. The design was modelled using CAD software and tested using finite element modelling software for deformations. Life cycle assessment and financial analyses are also presented. Future recommendations include testing the seeder in soil and simulating soil-machine interactions virtually.

Table of Contents

Abstract 2
List of Figures 5
List of Tables 6
List of Acronyms and Abbreviations 7
1. Introduction 8
2. Literature Review 9
2.1. Agronomic requirements for crop establishment 9
2.2. Functional and operational requirements for seeders 11
2.2.1. Seeder functional and operational requirements 11
2.2.2. Residue cutting device 11
2.2.3. Furrow opener 11
2.2.4. Seed covering device 12
2.2.5. Seed firming and seedbed firming devices 12
2.2.6. Depth control 12
2.2.7. Seed metering 13
2.2.8. Seed delivery 13
2.3. Alternative seeding options 13
2.4. Soil machine interaction 15
2.4.1. Soil properties 15
2.4.2. Field efficiency 17
2.4.3. Draft 18
2.4.4. Traction 19
2.5. Materials overview 20
3. Design Approach 21
3.1. Design criteria 21
3.2. Preliminary design iteration 21
3.3. Problems with initial design 23
4. Design Implementation 24
4.1. Gaspardo seeder 24
4.2. SOLIDWORKS model 28
4.3. Mechanical analysis 29
4.4. ANSYS verification 29
5. Prototype Testing 29

5.1. Experimental testing 29
5.2. Visual testing simulation 30
6. Design Evaluation 31
6.1. Environmental impact 31
6.1.1. Goal and Scope 32
6.1.2. Results 34
6.1.3. Interpretation 35
6.1.4. Data consideration 35
6.2. Socio-cultural considerations 36
6.3. Risk Matrix 37
6.4. Financial analysis 39
6.4.1. Economic considerations in Canada 39
6.4.2. Economic considerations in Rwanda 44
7. Conclusion 48
8. Acknowledgements 49
9. References 50
Appendices 54
Appendix A – Pugh charts from BREE 490 preliminary design 54
Appendix B – SOLIDWORKS models of Gaspardo seeder 56
Appendix C – Mechanical analysis calculations 62
Appendix D – ANSYS simulation results 65
Appendix E – Soil calculations 67
Appendix F – Preliminary GANTT Chart 70

List of Figures

Figure 1. Rise in maize production in Rwanda over the years (Source: Knoema, n.d.). 8
Figure 2. EarthWay Precision Garden Seeder (Source: Earthway.com, n.d.) 14
Figure 3. Glaser Seeder (Source: Johnny's Seeds, 2019) 15
Figure 4. Soil moisture content (Source: Uwitonz, 2016)…………………………………...16
Figure 5. Preliminary design of parallel seeding units. More units can be attached onto bar extension which was to be connected to a motor.. 22
Figure 6. Gaspardo seeder row removed from larger unit. 24
Figure 7. Team member, Leen, unbolting connections between seeder and single row unit. 25
Figure 8. Metering plate inside of seed metering device onto which seeds sucked by the vacuum connected by tube underneath.. 26
Figure 9. Disconnected vacuum seed metering device with power transmitting mechanism. 27
Figure 10. Seeder row without seed metering device. Ready to attach new seed metering device. 28
Figures 11 and 12. 3D renderings of Gaspardo seeder made in SOLIDWORKS. 28
Figure 13. System flowchart of the life cycle of a small-scale agricultural seeder. 33

List of Tables

Table 1. Results of the LCA
Table 2. Risk factor matrix
Table 3. Cost breakdown in Canada
Table 4. Depreciation table over a 5-year period in Canada
Table 5. Life cycle cost of mechanized seeder in Canada
Table 6. Cost breakdown in Rwanda
Table 7. Depreciation table over a 5-year period in Rwanda
Table 8. Life cycle cost of mechanized seeder in Rwanda

List of Acronyms and Abbreviations

AGRA	Alliance for a Green Revolution in Africa
CAD	Canadian Dollar
CIP	Crop Intensification Program
DBD	Dry bulk density
KNG-P1	Kigini Pedon
MISS	Mechanization & Irrigation for Smallholder Systems
NEPAD	New Partnership for Africa's Development
SMC	Soil moisture content
SSA	Sub-Saharan Africa
USD	United States Dollar

1. Introduction

Food needs in many developing countries are increasing with growing populations. It is increasingly important that agricultural productivity keep up with these growing demands. One such example is Rwanda.

In 2007, the government of Rwanda implemented the Crop Intensification Program (CIP), aimed at increasing the agricultural productivity of high-potential food crops to improve food security and self-sufficiency (Skoufias et al., 2013). As a result, Rwandan agriculture has seen a shift towards growing more maize, which was identified as a stable, priority crop in the CIP. (Fortune of Africa Rwanda, n.d.) (Fig. 1). Maize has been implemented widely in the country (albeit not being widely liked) as it is used in a variety of applications including feed production, biofuel production, and human consumption.

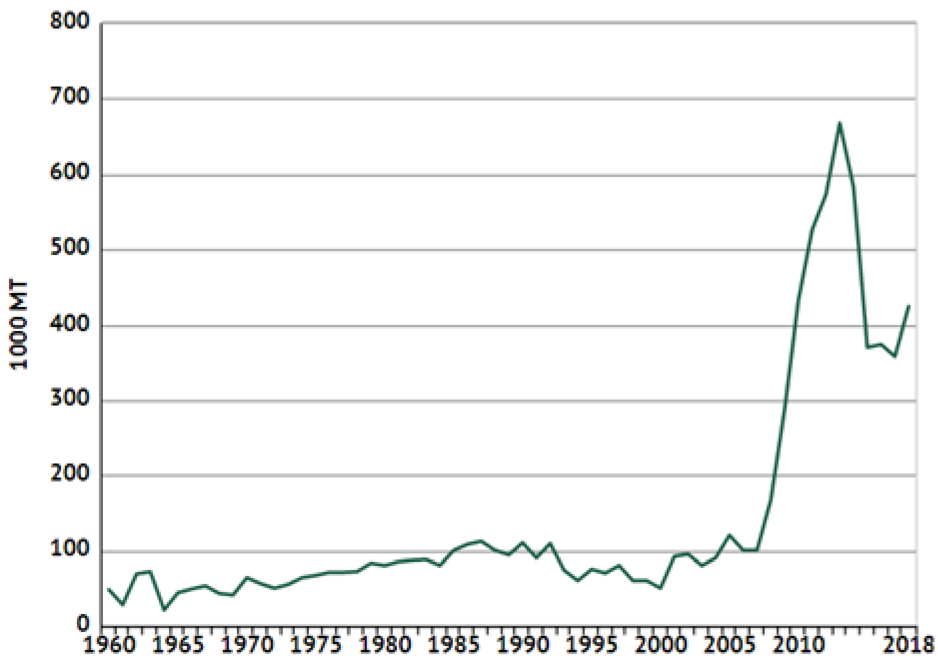


Figure 1. Rise in maize production in Rwanda over the years (Source: Knoema, n.d.).

Founded in 2006, the Alliance for a Green Revolution in Africa (AGRA) is an African-led institution for farmers that works on transforming smallholder farms into thriving businesses. Amongst their many goals, AGRA works on a Mechanization & Irrigation for Smallholder Systems (MISS) strategy made to accelerate growth rates of food production to achieve food security and improve the resilience of livelihoods of the rural population. Amidst their current projects, AGRA is working on improving sowing and transplanting small-scale farm equipment, such as the hand-hoe and other manual operations.

In fact, the availability of adequate levels of farm power is essential in increasing the agricultural production. Most of the farms in Africa still use manual agricultural tools and depend on human muscles as a power source, which constrains increases in agricultural productivity, results in a stagnation in the farm's income, and promotes drudgery, leading to poverty and hunger of the population. Farm power is therefore a crucial key component of small farm assets. It aims to accomplish tasks that are difficult to perform without mechanical aids, improves the quality of work and output products, as well as reduces the laborious work of farming activities. As Africa seeks to increase its output, its needs for farm power will also grow from its present heavy reliance on hand labor towards the use of draught animals or powered machinery (FAO, 2003). Other issues faced in small-scale sub-Saharan farms are the under-utilization of huge land potential for agriculture due to the decrease in labor available and the low productivity of human labor, as well as low yields due to failure in achieving optimal timeline of farming operations. This results in decreased yearly harvests.

This project is the continuation of an initial project aimed at developing a mechanized seeder for sub-Saharan African farmers to reduce farm losses by increasing efficiency and precision.

2. Literature Review

2.1. Agronomic requirements for crop establishment

Crop establishment refers to the process of seed germination, emergence and development through maturity (Murray et al., 2006). Lack of optimal crop establishment may result in yield reductions, replanting costs, excess weed growth, and much more. Seed/species characteristics, external physical, chemical and biotic environment as well as management influence plant establishment. Some management techniques such as irrigation, fertilizer application, and pesticide applications affect the seedling environment whereas harvest technique, storage method, and pre-plant seed treatments modify seed properties. In addition, planting machines are very crucial in crop establishment because they modify pre-existing seed and soil conditions and dictate seed placement within seedbed.

The first step of establishment, germination, begins with the uptake of water by the seed and culminates with elongation of embryonic axis. Oxygen demand may increase later, but no nutrients are required. Germination is dependent on seed quality, pre-sowing treatments, and having adequate oxygen, suitable temperatures, and moisture supply. Planting deeper in the seedbed with optimal depth of cover has proven advantageous as the moisture supply is higher and it is insulated from drying. It also improves the contact between seed and soil which is a vital part of establishment. Variations is seed size and shape can influence seeder performance, therefore some seed metering devices often can tolerate a range of sizes and shapes, while others are designed for specific crops. If the degree of soil disturbance is too high when opening a furrow to place the seed, there is a risk of increased moisture loss and reduced water conductivity.

After germination comes emergence, when the seedling emerges from the surface. It is critical in seeding operations to maintain a uniform depth. The optimum seeding depth is affected by the depth of furrow relative to the surface, which affects the moisture availability to the seed, and the depth of soil covering the seed, which affects emergence. Raised beds or ridges can be used to place excess soil. Press wheels may be used to modify the depth of cover and create a depression in the soil which concentrates runoff and improves moisture status around seedlings.

Establishment is when the seedling is no longer dependent on seed reserves. Land preparation has a large effect on establishment as tillage layers can restrict root growth and moisture movement.

There are numerous planting patterns used depending on crop type, tillage practice, and available tools. Broadcast planting involves random scattering of seeds. Drill planting is random dropping of seeds into definite rows albeit randomly spaced. Precision drill planting involves definite rows and accurate placement at equal intervals. Hill drop planting is the accurate placement of groups (or hills) of seeds. Check row planting is planting in a square-grid pattern, in equidistant, perpendicular rows. Dibble (or punch) planting involves placing seeds into individual rows rather than defined rows. Drill and precision drill planting are the most extensively used, especially for maize production.

2.2. Functional and operational requirements for seeders

2.2.1. Seeder functional and operational requirements

Seeders should chiefly open a furrow, meter the seed, deliver the seed into the furrow, and cover and firm the seedbed. Inter-row spacing requirements depend on the furrow openers (spacing may be adjustable) while intra-row spacing requirements depend on the seed meter, which discharges seeds at a predetermined rate (Murray et al., 2006). Seed delivery should minimize bounce and displacement to maintain accuracy. Seeder are typically classified by the number of rows planted, power source, attachment to the power source, and planting pattern.

2.2.2. Residue cutting device

Functional requirements of residue cutting devices are cutting crop/weed residue to be displaced sideways, cutting/disturbing hard soil layers, and cutting plant root material so that seedbed isn't further disturbed by the furrow opener. Residue cutting is especially important if using tine type furrow openers while soil cutting is important when using negatively raked furrow openers under high strength soil conditions or when the opener alone cannot create enough soil tilth to cover the seed. Simply adding weight to better penetrate soil may result inside wall and furrow base compaction, which is detrimental to seed establishment.

Operational requirements to meet these functional requirements include providing an adequate vertical force and sharp cutting edge to ensure residues are cut and not simply pushed into soil. As disc diameter increases, so do cost, vertical force, and draft requirements. Under heavy loads, small discs push rather than cut residue, but large discs don't penetrate as well. A rake angle of around 45 degrees is ideal. The shape of the cutter determines the ratio of cutting to disturbance. Residue cutters can be fitted with scrapers to remove excess soil buildup.

2.2.3. Furrow opener

Functional requirements of furrow opening devices are opening a furrow at a maintained depth, minimizing soil disturbance, avoiding over-compaction, and allowing an appropriate amount of soil to flow back into the furrow. Some furrow openers may displace soil down and out, up and out, or many other ways.

Operational requirements of furrow opening devices are being rigid in its working position, being adjustable to allow for changes in depth and spacing, having an effective depth controlling mechanism, and minimizing seedbed disturbance.

2.2.4. Seed covering device

Functional requirements of seed covering devices are transferring displaced soil to cover the seed, regulating depth of cover, and re-levelling the seedbed.

Operational requirements of seed covering devices include being able to be selected and adjusted, not displacing seeds and maintaining depth, and minimize disturbance that might impede emergence

2.2.5. Seed firming and seedbed firming devices

Functional requirements of seed firming devices are firming the uncovered seed into the base of the furrow and reducing the possibility of seed bounce by assisting the placement. Operational requirements are correctly positioning the seed firming relative to the furrow opening device and not dragging seeds out of position.

Functional requirements of seedbed firming devices are like those of seed firming and include improving moisture availability, improving emergence prospects by reducing light penetration, and reducing the potential for damage to the seed. The effect of seedbed firming becomes more apparent as moisture becomes limiting. Operational requirements of seedbed firming devices are that the shape of the device would match the furrow shape and that the mounted devices would have adjustable pressure.

2.2.6. Depth control

Ideal planting depth for corn ranges from 4.5 to 5.7 cm (Luce, 2016). Functional requirements of furrow opener depth control devices are that they open the furrow to the specified depth and maintain uniformity of that depth along the furrow. Operational requirements of furrow opener depth control devices are that they maintain depth over the range of soil types and surface conditions, such as uneven ground, and that they can be easily adjusted (Murray et al., 2006).

Some more precise depth control devices may employ sensors, such as moisture detectors, to gauge the depth and adjust accordingly. Depth control devices may be 'frame section gauging' or 'individual row gauging'.

2.2.7. Seed metering

Functional requirements of seed metering devices are that they meter the seed at a predetermined rate and cause minimal damage to the seed. To meet these requirements, the operational requirements of seed metering devices include being able to meter many types of seeds at a range of rates and being able to maintain that rate and spacing. Residue accumulation might affect seed meter performance. Seed damage may increase with meter speed or seed size; thus, one must be careful when operating seeders at high speeds.

2.2.8. Seed delivery

The functional requirements of seed delivery are to convey the seed from the seed meter discharge point to the seed placement, maintain speed accuracy during seed conveyance, as well as allow the seed to be deposited either on the soil surface with right seed spacing within the furrow and along the row (Murray et al., 2006). The operational requirements of seed delivery systems depend on the type of seed metering system used. On drill planters, design of the seed delivery system has little influence on the overall outcome, as long as seed flow through the system is duly inhibited and the exit velocity is low enough to ensure that seeds are placed on the base not the adjacent. However, on precision planters, the design of the delivery is very important because the functional requirement is to convert seed metering accuracy to placement accuracy.

2.3. Alternative seeding options

In highly industrialized agriculture, seeding operations are primarily done by large scale tractors implements which can seed dozens of rows at a time. The purpose of this design was to scale down that operation to under ten rows and simplify the mechanisms such that any farmer could easily operate and maintain.

There exist many small-scale precision seeders on the market (Johnny's Seeds, 2019). The EarthWay Precision Garden Seeder is a low-cost, push-type seeder, most commonly used in home gardens (Fig. 2). The Glaser Seeder is a pull-type seeder whose body opens a seed drill into which seeds are placed (Fig. 3). None of these seeders however are motorized; they rely solely on human power. Components of these existing models were considered in the premilinary design criteria.

Figure 2. EarthWay Precision Garden Seeder (Source: Earthway.com, n.d.)

Figure 3. Glaser Seeder (Source: Johnny's Seeds, 2019)

2.4. Soil machine interaction

2.4.1. Soil properties

Agricultural soil is subjected to two types of machinery traffic namely wheel traffic and tillage traffic. The former compacts the soil profile while the latter loosens and redistributes through part of the depth profile. The soil response to each traffic is a consequence of both previous operations and total natural forces acting in the interval (Raghavan, Alvo & McKyes, 1990). That is why in practice the effects on soil properties caused by the two traffic are dependent on each other. Traffic parameters, and soil properties at time of traffic define the soil response to compaction. The response of soil to compaction is described in terms of changes in dry bulk density (DBD), porosity, penetration resistance (PR) as functions of applied pressure and soil moisture content (SMC) (Raghavan, Alvo & McKyes, 1990). Hence, it is important to consider the above parameters when developing any agricultural machine. The following discusses the soil properties in Rwanda.

Since it was impossible to find soil data for every region where maize is grown in Rwanda, one location was used as a reference. The soil data used is from a study which was carried out in the northern part of Rwanda in Musanze District (where a profile on Kigini Pedon was excavated (KNG-P1)).

According to the studied soils, the particle distribution of clay, silt, and sand were found to be 16.8%, 20.1%, and 63.1%, respectively (Uwitonze, 2016). The relative proportions sand, silt, and clay in the soil is what called soil texture. It is the most permanent characteristic of soil that influences several other soil properties such as soil structure. When the results of clay, silt and sand were analysed using the USDA Soil Taxonomy, the soil texture was found to be sandy loam. The studied soil also showed bulk density to be 0.44g/cm^3 (Uwitonze, 2016). Bulk density is the weight of dry soil per unit of volume. Bulk density is a measure of soil health and soil compaction. It affects soil porositiy, infiltration, and rooting depth. The ideal bulk density for plant growth on sandy loam soils is less than 1.4g/cm^3. The low bulk density found may be attributed to high content of organic matter found in the soil. It suggests that the soils are not compact, plant roots can penetrate easily and better soil tilth hence leading to easy tillage, seedling emergence, and root development (Uwitonze, 2016). Moreover, particle density was found to be 1.93 g/cm^3. Particle density is the average composition of mineral density in the soil. Most soils particle density is close to 2.65g/cm^3 because the dominant mineral in particle density is quartz (has a density of 2.65g/cm^3).The small value found is attributed to small amount of micas, quartz, and higher organic matter content in the studied Pedon (Uwitonze, 2016). Nonetheless, particle density varies little between minerals and has little practical significance except in the calculation of soil porosity. Furthermore, soil porosity is a measure of the amount of spaces or pores in the soil that is occupied with water, air, and other fluids. A combination of texture, structure and organic matter determines the porosity. Soil porosity is also an indicator of the degree of compaction. The soil porosity was measured to be 77.23% and attributed to relatively high organic matter content in the soil. Soil resistance is also another soil property. Soil resistance is commonly used as an indicator of soil strength (Uwitonze, 2016). Soil strength affects root growth, seedling emergence, aggregate stability, and compaction. Soil resistance is directly proportional to bulk density. Soil resistance found is 2.39kg/cm^2. This number is attributed to low bulk density found in the soil and shows that the topsoil is loose and facilitates root growth. Lastly, soil moisture content indicates the amount of water in the soil. Lastly, soil moisture characteristic curve is dependent of organic matter content and particle size distribution (Uwitonze, 2016). The results found suggest a high retention capacity with a gradual decrease when suction potential increases. This fact may be attributed to high organic matter found in the soil. Soil organic matter enhances soil water retention because of its hydrophilic nature and its positive influence on the soil structure (Uwitonze, 2016). The figure below shows the soil moisture content.

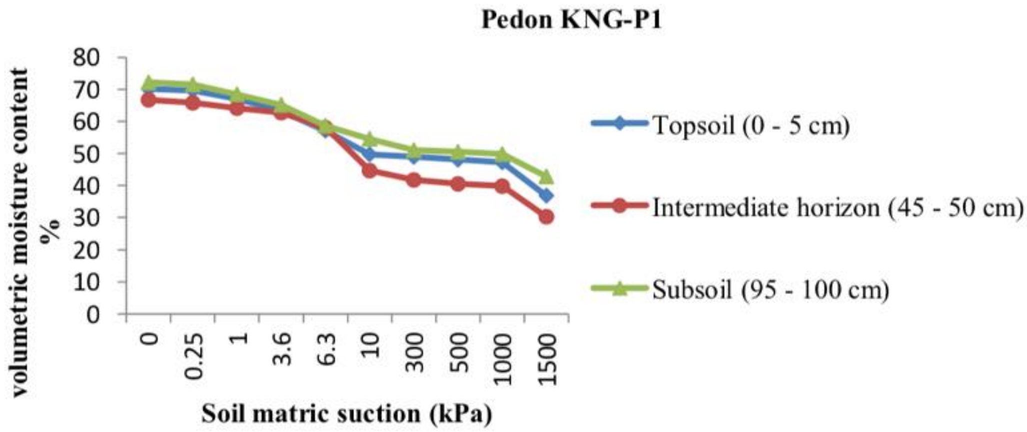


Figure 4. Soil moisture content (Source: Uwitonze, 2016)

2.4.2. Field efficiency

Rate and quality measure how the operation of firm machines is accomplished. Rate is an important measure because agriculture is sensitive to season and weather. To determine the performance of a planter, field efficiency must be calculated. Field efficiency is the ratio of effective field capacity to theoretical field capacity, expressed as decimal value. It shows how well machinery is suited for use in a particular field (Condra et al., 2017). It examines the relationship between actual productive time in the field and time spent in the field. Actual productive time in the field for planting operations is time spent planting. Field efficiencies for row crop planters range from 50 to 75 % for planting speeds of 6.5 to 11.0 km/h (Condra et al., 2017). Theoretical capacity, planter's speed, field pattern, size and shape, soil conditions and system limitation are factors that affect field efficiency of a planter. Field efficiency decreases with increase in theoretical capacity. Theoretical field capacity is defined as a machine running at its maximum capacity at 100 percent of its effective width at a given speed during the machine’s operation (Condra et al., 2017). Field efficiency improves when length of the row is doubled, and width of planter remains unchanged, because the time used by a planter to travel through the soil increases with respect to its turning time. However, large fields do not necessarily have greater field efficiencies than small fields (Condra et al., 2017). Because if travel speed is kept constant and turning radii is identically proportional to width, the pattern efficiency will remain the same even if both width of the field and seed planter are doubled.

The improvement of field efficiency can be made by analyzing and varying the pattern of field operations. Field pattern is closely related to the size and shape of the field; however, some pattern considerations can be studied independently of field configurations (Hunt, 2008). In order to establish an efficient field pattern, the amount of field travel needs to be reduced. The number of nonworking turns, travel distance and nonworking travel inside the field should be avoided. Another factor is to modify the choice of a field pattern because repeated machine travel over an area of the field may cause compaction in some soils (Hunt, 2008). Contour planting, and contour structures are the most important soil conservation measures to modify field pattern. For instance, rectangular fields have high field efficiency compared to irregularly shaped fields because of their excessive turning time. Even when the irregular fields are straight sided, the ration of turning time to operating time will be high.

The effectiveness of a planter largely depends on its forward speed and the power unit used to pull it through the soil. Row planting involves the movement of soil from one place to another. When travel speed increases, field efficiency decreases (Hunt, 2008). Increased field speed will decrease the actual working time required; however, if the time lost remain basically the same, field efficiency will be less as in the case of a seeder. Consequently, operators should not use slow speeds to keep the numerical field efficiency high. However, there are so many factors that affect field speeds such as overloading the machine's functional units, inability of the operators to steer the machine accurately and loss of function and structural damage to the machine due to rough ground surface (Hunt, 2008).

2.4.3. Draft

The power required to pull a planter through the soil at a given ground speed is dependent of its draft and traction developed by the power unit (Walter, 2013). Draft is the force required to pull farm implement through the soil. The draft force is located at the point where the tool is attached to the power unit called the hitch. Most of the time this power unit is a tractor. Moreover, draft force moves in the same direction as the travel of planter. To move a planter in the soil at a given speed, the total amount of draft force is required. Draft requirements can be obtained from engineering publications and manufacturers. To calculate the draft force of the planter, width, depth, speed at which is pulled, and soil resistance are required. Soil resistance is based on soil characteristics such as moisture content and soil texture. For example, a dry sandy loam has greater draft than moist sandy loam soil, and hence require more power to work (Walter, 2013). This is caused by the lubricating effect of moisture films surrounding soil particles and decrease in soil strength transmitted by the moisture (Walter, 2013). In addition, fine textured soils require extra power to function and becomes difficult to work with when their moisture is too low. In order to save power and maximize the effectiveness of the machine, seedling should happen when soil is most friable (when moisture content is near field capacity) (Walter, 2013). The speed of the machine is directly proportional to draft. This means that if a field has a mixture of soil types, the tractor must be sized according to the soil with the most resistance.

2.4.4. Traction

When a planter is pulled through the soil, the tractor (power unit) must overcome draft forces created by soil resistance in order to move forward. It is easily done because modern tractors are designed to transmit greater power to the soil (Walter, 2013). The transfer of power to the soil is done through the drive axle on which tires and wheels are mounted. Transmitting that power requires large frictional forces or traction (the force of forward motion derived from contact between the tractor's tires and soil) at the soil surface which converts the torque or rotary motion of the tractor's crankshaft into forward motion.

The main purpose of a planter's tire is to support its weight while moving with a minimum amount of resistance over the soil surface (Walter, 2013). The wheels rearrange the soil particles in order to provide shear strength to the soil that support the weight and generates forward motion. Shear strength is a measure of the force needed to deform the soil. Agricultural soils are a mixture of sand, silt, and clay and therefore derives its shear strength from internal friction and cohesion. Studies show that the strength of the clay soil depends on its cohesive properties while sand soil depends on the force (Walter, 2013). When the planter's tire passes over a field surface, soil deforms vertically in response to its weight and horizontally to generate traction. The amounts of vertical and horizontal deformations of the soil are rolling resistance and wheel slippage, respectively. Rolling resistance is achieved when a planter that is constantly exerting effort climbing up hill against the downward pull of gravity has less power available for forward motion. Whereas, when wheel slippage is 100%, all power is consumed in soil deformation and forward movement cannot be achieved (Walter, 2013). Zero-wheel slippage means there is no soil deformation and hence no power. However, certain amount of slippage is desirable. Wheel slippage on planters can be managed by ballasting the tires and is usually specified by the manufacturer. However, planters are ballasted to maximize tractive efficiency, which is the fraction of power available at the axle that is transmitted to a planter through the drawbar. Over-ballasting a planter may lower wheel slippage, increase rolling resistance and may also damage the drive train (Walter, 2013).

2.5. Materials overview

The selection of the right material and treatment for a particular application of a farm machine is crucial from the standpoints of cost, durability, and machine performance. Components should be designed to use the lowest cost materials that will perform satisfactorily and have an adequate life. In the case of the small-scale agricultural seeder, it might be necessary to substitute high-cost materials and expensive treatments for low-cost materials to make up for deficiencies in the original design. Typically, agricultural machines are consisted exclusively of iron and steel. Brass, bronze, babbit, and wood are used less for small parts such as bearings. Belts, conveyors, tires, and synthetic rubbers are used in a limited extend where resilient mountings are advantageous (Anderson, 1953). Recently, a lot of research has been going on around the further development of the material parts and components used in modern agricultural machinery. Research suggests that aluminum will be used for future applications where resistance to corrosion and light weight are advantageous (Anderson, 1953). Plastics can also be used where weight saving and resistance to wear are important (Anderson, 1953). Considering that it is not widely spread yet, both aluminum and plastics are relatively expensive to use in order to build the small-scale seeder. It could be a possible option in the future as these two materials become more common.

The strength and durability of a farm implement largely depends on the type of materials used in building it (Smith, 1948). The selection of the materials is based, but not limited to, the following factors: stress-strain relationships, deflection and stability of the machine, and corrosion resistance. In the case of this project, choosing a material was not necessary as there was only one seeder available to redesign (explained below).

3. Design Approach

3.1. Design criteria

The following design criteria were established through consultation with the clients, as well as through discussion with mentors, advisors, and technicians:

Functionality. The design must function and be suited for the soil, climatic and weather conditions of Rwanda. It should be easy to operate and work either as an implement to a tractor or drought animal.

Safety. The design must pose no risks to the safety of the users, or small-scale farmers. Each element of the system must be carefully designed to minimize any risk of danger. The design must be discussed with experts to ensure that it meets all safety codes and engineering standards.

Low maintenance requirements. The design must require minimal maintenance from the farmer or owner of the machine. It should not require any intervention apart from being able to set it up and attach it to the tool that will be driving it. The different components of the seeder should be self-sustaining and should not need to be replaced on a yearly basis.

Ease of operation. The system must be easy to operate and understand. Small-scale farmers should be able to understand the designed system without previous knowledge on the matter, as well as operate the machine with ease.

3.2. Preliminary design iteration

The initial design from BREE 490 was a simple seeder implement that consisted of two parallel beams which supported the seeding devices: a notched disc coulter to cut residue; a concave disc furrow opener; a chain seed covering mechanism (not pictured); a depth gauge wheel; a hopper with an inclined plate seed meter; and a drive wheel which was to drive the seed metering device. These units were to be connected in parallel by another beam which could connect to the motor (Fig. 5). The motor was to be self-propelled with a triggering mechanism similar to that of a walk-behind lawn mower; a simple four-stroke, gasoline-powered internal combustion engine produced by Briggs and Stratton was to be used in preliminary prototypes.

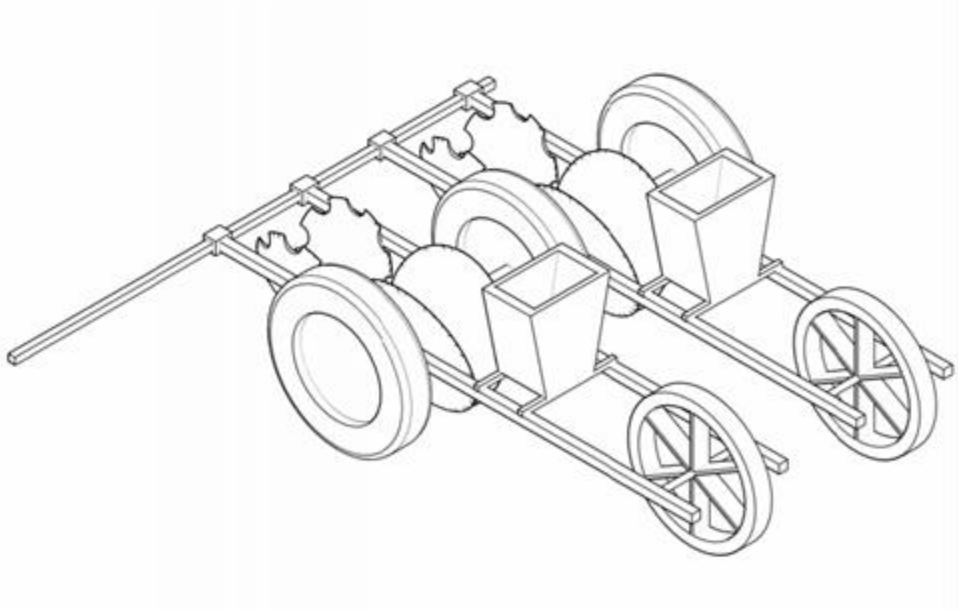


Figure 5. Preliminary design of parallel seeding units. More units can be attached onto bar extension which was to be connected to a motor.

It was not deemed necessary to have all components of seeders described above in the design. Often, residue cutting devices can function as row preparation devices (Murray et al., 2006). Similarly, the drive wheel can serve to firm the seedbed. The design selected consisted of a residue cutting device (which also functioned as row preparation), furrow opener, seed covering device, depth gauge, seed meter, and drive wheel (which also functioned as row firming).

Each component of the seeder had a different function therefore unique criteria for selection. Pugh charts were used to select between options for residue cutting, furrow opening, and seed covering devices (see Appendix A). A simple depth gauge wheel system was used to control seeding depth. There exist many seed metering devices (Garner et al., 2015; Deckler, 1991). However, according to Sims and Kienzle (2006), the inclined plate seed meter is most common over horizontal plate seed meters manufactured in southern Africa because they can handle ungraded seed better.

One important criterion was to give the farmer flexibility in the number of rows they choose to seed. Hence the design was to be modular in a way that any number of single row units could be connected to a motor.

3.3. Problems with initial design

Upon returning for BREE 495 to continue, the team first sought to improve upon our preliminary design. Marc Samoisette, the Chief Agronomy Technician for the Macdonald Farm has a lot of expertise on seeders and other agricultural equipment, hence had a lot of helpful practical feedback. He strongly recommended adding a separate component to push aside residue in addition to the residue cutting device already there, since it is being designed for conservation tillage. He recommended having two wheels as depth gauges (one on each side) so that the machine is better balanced. He said that it is better to have a flat rather than curved disc for the furrow opener to prevent compaction. For covering, he recommended cast wheels over the chain closer because they are better in no-till situations. Many seeders at the farm used finger seed metering, which he recommended as they can be used for any seed type. This was deemed a better option since if the price goes up, being able to seed more crops with the same seeder would be a better sell. He recommended designing only for two rows and making it a very strong sturdy design that can last in conservation tillage, rather than a variable-row implement.

Scott Manktelow, Laboratory Superintendent at the Machine Shop, also had suggested to focus on the mechanical design of the pull implement rather than the motor. He recommended designing it such that it can be pulled by anything (motor, draught power, human, etc.). This would also broaden the market for who can use it.

Other concerns brought up was what to do in the case of uneven ground and how to transport the unit (addressed below). Dr. Raghavan said that levelling was not a concern of the seeding operation and would simply require a prior levelling operation, especially in the case of conservation agriculture.

Ultimately, as funding was unavailable and parts were very difficult to find, it was not possible to move ahead with the preliminary designs with Marc's recommendations. It was considered to order existing seeders, such as the Earthway or Glaser seeders, and disassemble them for their parts. However, Marc pointed out that these seeders are designed for conventional tillage, thus much flimsier, and would not be suitable for conservation tillage, as is the case for this project.

After much deliberation, the best course of action was to use an old seeder available and not-in-use at the farm to redesign to match as closely as possible our original design. The frame was sturdy enough, as it was designed for large scale operations, and it came fitted with most necessary parts of a seeder. It was decided that two rows would be taken from this seeder and reworked and attached together into a pull implement that could be used with any power source. Some parts would need to be changed, the seeder tested in real soil, and any necessary changes made in iterations. Unfortunately, this was only begun but not completed as the team no longer had access to campus facilities due to the COVID-19 outbreak.

4. Design Implementation

4.1. Gaspardo seeder

The old seeder at the farm, referred to as the Gaspardo seeder (Fig. 6), was no longer being used for seeding due to its seed metering mechanism. The Gaspardo seeder employed a vacuum seed meter, which, as Marc described, volatilized and sprayed dust directly in the direction of the operator. This posed a human health and safety risk as this dust consisted of any pesticide or fertilizer the seeds contained.

Figure 6. Gaspardo seeder row removed from larger unit.

Therefore, the primary task was to remove the vacuum seed metering mechanism. In order to do so, it was first necessary to separate the two rows from the larger seeder. This proved to be a challenging step as most components were bolted on and connected in multiple ways, including the frame, power transmission, and the vacuum seed meter (Fig. 7).

Figure 7. Team member, Leen, unbolting connections between seeder and single row unit.

Taking it apart also allowed for better insight into how the parts are connected and how the mechanisms worked. One such mechanism was the power transmission and vacuum connected to the hopper and seed meter. A rod that runs through the large red piece in Figure X turns, causing the long red shaft to turn. This shaft is connected to what appears to be a differential inside the seed meter, which causes the seed plate to turn (Fig. 8), singulating seeds, and dropping them into the furrow. Once the seed meter was removed, the unit was ready to hold a newer, safer seed metering device (Fig. 9 and 10). The remaining parts were deemed okay for use. These included a residue cutter, furrow opener, and cast wheel furrow closer (see Appendix B). Transporting this unit would be relatively simple; one would simply need to lift it to rest on the cast wheels in the back, which can be easily driven anywhere and attached or stored.

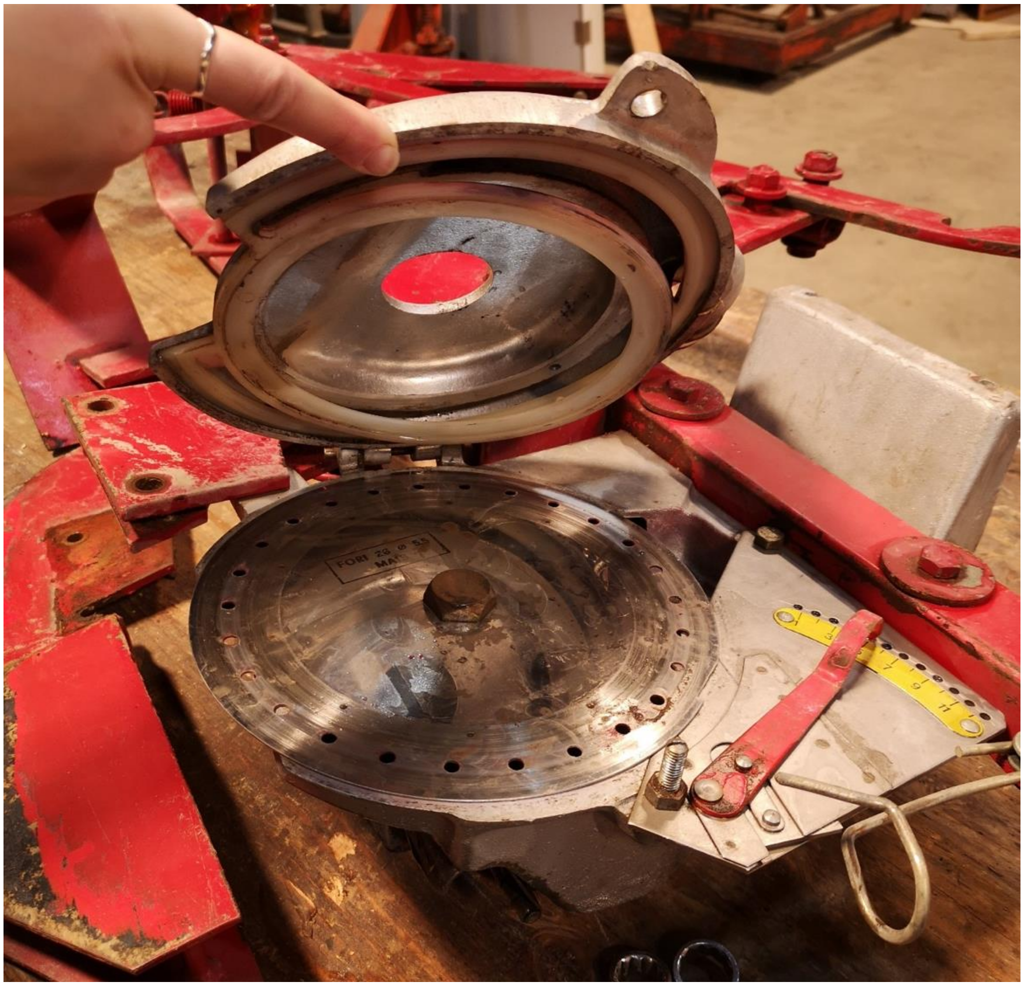


Figure 8. Metering plate inside of seed metering device onto which seeds sucked by the vacuum connected by tube underneath.

As it was not possible to order and install a new seed meter before facilities were closed, emphasis was instead put on determining constraints to a hypothetical seed meter that could be attached when the opportunity comes. The Gaspardo seeder was designed in SOLIDWORKS and mechanical analysis was performed to determine the maximum weight that could be withheld by the beam that would carry the new seed meter and verified in ANSYS.

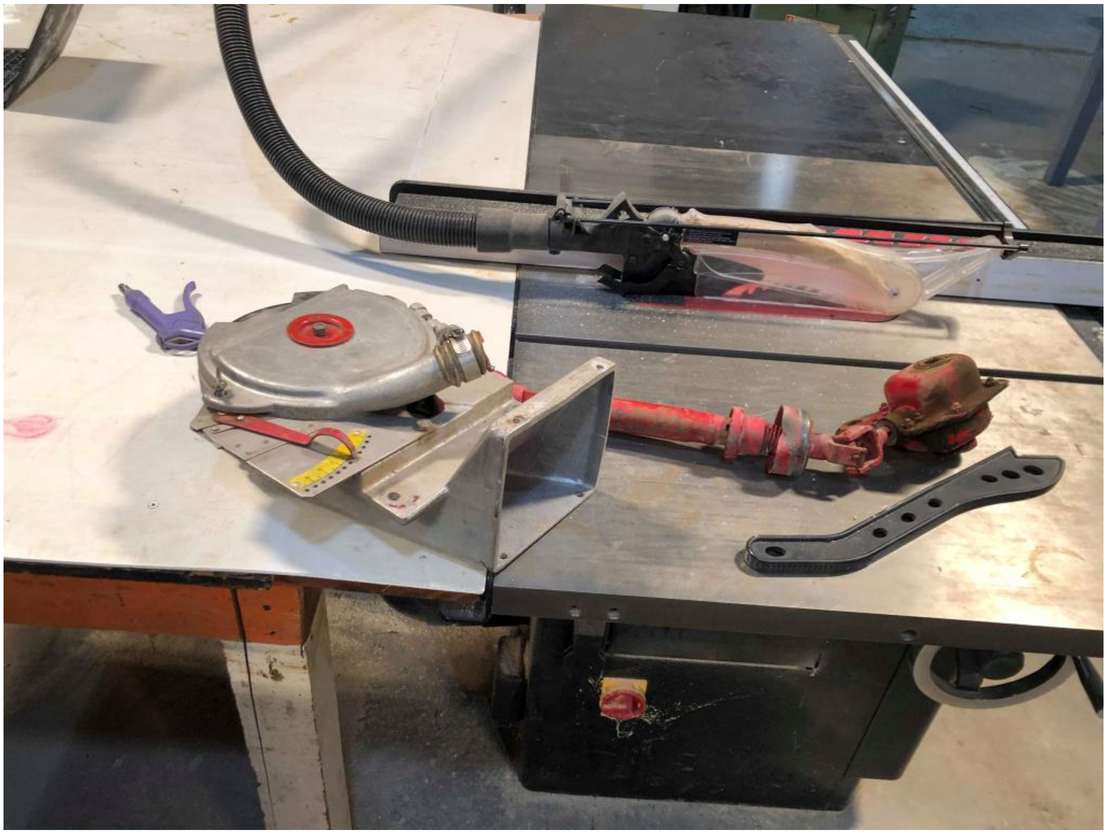
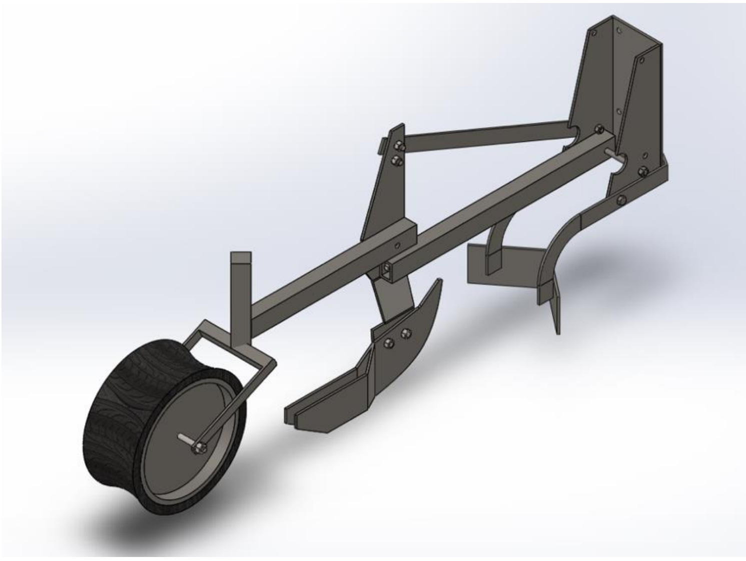


Figure 9. Disconnected vacuum seed metering device with power transmitting mechanism.

Figure 10. Seeder row without seed metering device. Ready to attach new seed metering device.

4.2. SOLIDWORKS model

Measurements of crucial components of the Gaspardo seeder were meticulously taken and noted. These measurements were translated to a 3D model in SOLIDWORKS (Fig. X)(see Appendix B). The hope was that the new seed meter, and any changes we deemed necessary after testing the seeder, could be easily added in the 3D model. Some modelled parts were later used in ANSYS to verify mechanical analysis.



Figures 11 and 12. 3D renderings of Gaspardo seeder made in SOLIDWORKS.

4.3. Mechanical analysis

When attaching a new seed meter, it was important to make sure the beam could support the weight of the seeder. It was found that the beam could support up to 27601.17 N of force. Calculations can be found in Appendix C.

4.4. ANSYS verification

In order to verify that this was in fact reasonable, the beam was modelled in SOLIDWORKS and exported to ANSYS, a finite element modelling software which can determine the deformations, stresses, and strains in all parts of a body given the loads and boundary conditions it is subject to. The beam was assumed to be made of structural steel, have two supports where it was bolted or welded to two other members of the seeder and the load was treated as a downward directed force, with a magnitude of 27601.71 N. The maximum total deformation was 0.13 mm, maximum deformation directed downward was 0.12 mm, maximum strain was 0.001 mm/mm, and maximum stress was 170.51 MPa (see Appendix D). Therefore, for any seed meter which exerts a force under 27601.71 N, the beam will deform only tenths of a millimeter. Any seed meter under 2813 kg would therefore be a reasonable choice for minimizing deflections in the beam.

It was also planned to model the furrow opener in ANSYS by simulating the force exerted by soil (see Appendix E) and support reactions to determine possible failure. However, this could not be done as the team did not have access to school computers and was only able to download ANSYS less than a week prior to the deadline due to technical difficulties.

5. Prototype Testing

5.1. Experimental testing

Unfortunately, the team was not able to complete assembling the seeder with new parts and attaching the two rows together into a pull implement. If the assembly had been completed, the next step would have been to test the seeder in real soil. Testing would have been done either at the farm if the soil had thawed by then or at the shop, by creating a plot of soil to mimic that of a conservation tillage.

When testing seeders, there are important performance indices to evaluate. In a laboratory, seed rate, seed rate instability, unevenness of seed distribution in the working width can be measured. In the field, average working depth, average width of strips, average depth of seed incorporation, and measures of distributions of each such as standard deviation or coefficient of variation can be measured for every run of the test (Dragos et al., 2016). It is important for any seeding operation that rates and spacings are consistent and even. Nonuniformity would compromise the health of growing plants.

5.2. Visual testing simulation

Simulation and computer-aided engineering (CAE) enables one to perform virtual testing of equipment. In the case of simulating agricultural processes, an important aspect is to consider the handling of the material that the machine is interacting with. Discrete Element Method (DEM) is a particle-scale numerical method for modeling bulk behavior of granular materials including grains, seed, crops, soils, and stems. DEM allows to recreate the behavior of these materials and analyze how they will interact with a piece of equipment during a range of operation and process conditions (ABAQUS, n.d.).

An example of such software is EDEM, used for the design, performance testing, and optimization of agricultural machines such as the mechanized seeder. Using this software, bulk material simulation as part of the design process can bring benefits to agricultural equipment such as predicting the flow of seeds to deliver optimal flow properties, identify the risk of blockage in the seeder due to high flow rates, model interaction responses with soils and machine, predict kinematic responses due to impacts with compressed soils or large rocks, as well as perform testing out of season without having to ship the built prototype to Rwanda and reducing the need for physical prototypes (DEM Solutions, 2020). Unfortunately, access to this software was not available and virtual simulation was out of the scope of the project. However, this is still a promising endeavor for future trials.

6. Design Evaluation

6.1. Environmental impact

Agricultural production has a huge impact on the environment. Although its share of the gross domestic product has declined steadily over several decades, farming still exerts a significant impact on the environment. The increase in agricultural productivity over the 20th century, and the rise in mechanization lead to an increase in labor productivity, an intensive use of fertilizers and pesticides as well as progress in animal husbandry. Although his resulted in an increase in yields, the excessive use of these inputs has resulted in problems such as eutrophication and toxicity. It is also the main source of several major emissions such as methane (CH_4), nitrate (NO_3), and ammonia (NH_3) 93% of which comes from agricultural sources (Thöni, Seitler, & Matthaei, 2007). Hence, the study of agricultural production systems is a priority in order to ensure minimal effect on the environment. The proposed designed does not currently include a fertilizer spreader, however, the design team will look at the environmental impact that it generates throughout its life cycle.

In order to help assess theses impacts, a Life Cycle Analysis (LCA) is conducted. This will help the design team easily identify the most polluting stages of the process and use them as a guide to develop enhanced methods and processes in the future.

An LCA is a detailed analysis of a product; it describes the entire life span of the product. It encompasses the production of raw materials, the manufacturing process of the machine, logistics, use, and ends with the machine's reuse, recycling and disposal (ART, 2007). Both the product's use phase and end-of-life disposal phase depend on consumer behavior; nevertheless, they are critical stages in a product's use phase cycle. During the manufacturing phase of the seeder, every stage has an impact on the environment, such as energy usage and CO_2 emission and waste.

The LCA is divided into four stages. The first stage includes defining the goals and scope of the study by describing the product that is to be assessed. The second stage is the inventory, which represents the collection of the data from all processes of the product's life cycle. This includes the acquisition of raw materials till the development of the final product. During this stage, energy, raw material requirements, environmental emissions and discharges relating to the product are computed. These data can be used to calculate the discharge from all the processes of the product's life cycle. The third stage is the impact assessment stage, in which the inventory data are translated into their effects on human health, ecological health and resource depletion. The last stage of this process is the interpretation stage which is based on an analysis of the impact assessment results (Horne et al., 2009).

6.1.1. Goal and Scope

The objective of this study is to analyze the environmental impact of using a small-scale seeder, manufactured in Canada, and used on a small-scale farm in Rwanda from a life-cycle perspective.

The functional unit chosen for this LCA is the usage of 1 seeder over one year. Assuming that the seeder has an average lifespan of 15 years and is used twice per year, the key parameters are a lifespan of 15 years and used 1 every season. The reference flow is the number of seeders needed to satisfy the functional unit of 15 years, consequently, it would be 1/15 seeder. Figure 13 describes the life cycle of the prototype from its manufacturing phase, till its end of life.

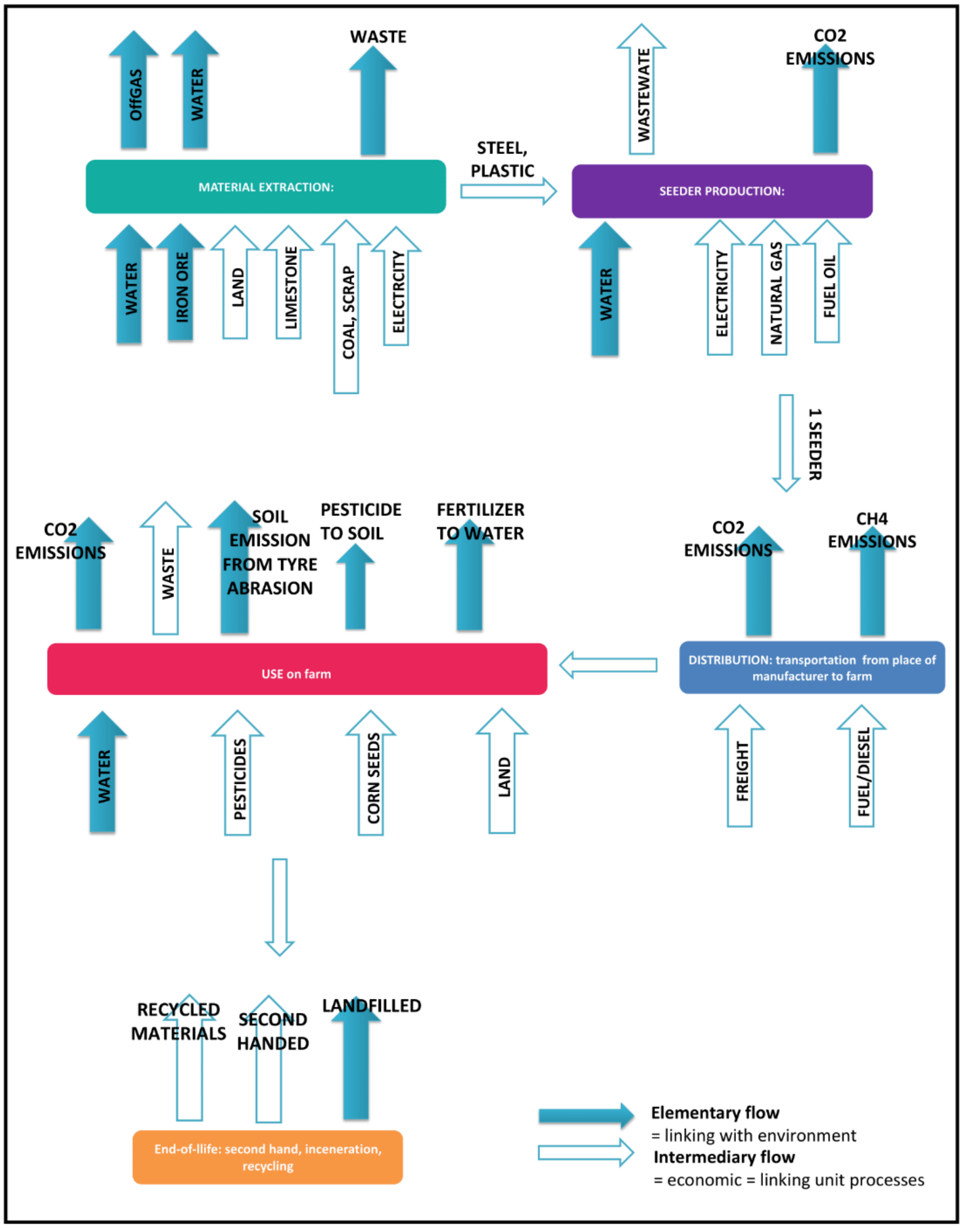


Figure 13. System flowchart of the life cycle of a small-scale agricultural seeder.

The blue arrows in Figure 13 represent the elementary flow linking the unit process with the environment, whether they are inputted directly from the environment or outputted straight to the environment such as the emissions. The white arrows represent the economic or intermediary flows, which link the unit processes together or represent the materials, energy, services required by the activity. The land is considered as an intermediary flow as it is providing the service for agricultural activities, although it could also be considered as a resource to support those activity, in which case it is considered as an elementary flow. Electricity however is considered as a product and not an input from the environment and is consequently regarded as an elementary flow. The production of electricity involves generators and engines in a power plant, as well as different steps such as material extraction, acquisition and processing. In the system above, the preceding processes are not included in the boundary of the study and electricity is only considered as a production from that system. The raw materials, natural gas, electricity, fuel oil and other materials used to manufacture the seeder, as well as the fuel/diesel and freight are considered products of previous systems which are not included in the system boundary of the Figure 13. They are thus represented by a white arrow, linking the processes together. Waste is assumed to be recycled and recovered and used in some way, thus considered as intermediary flows.

Concerning the end-of-life of seeder, three different options could be considered: recycled materials, second handed, or landfilled. The landfill option is represented as an elementary flow, the seeder being discharged back into the environment. The recycling options is represented as an economic flow since it would be incorporated back into the recovery and recycling facility. The secondhand option is also assumed to be a product, since it has been produced by a previous cycle and is going to be incorporated in a new life.

The data used for this study has been extracted from the Impact2002+ preprocessed copy of the Ecoinvent database (https://mcgill-my.sharepoint.com/:x:/g/personal/sreedurga_cherukumalli_mail_mcgill_ca/EWS28834E8lHjgyD5SXtK3sB9bzFkid0d8VGXjbOYu_p0w?e=k6RmaG).

6.1.2. Results

Table 1. Results of the LCA

	Climate change (kg CO2_eq)	Human Health (DALY)	Ecosystem (PDF_m^2_y)	Resources (MJ)	Water Withdrawal (m^3)
Manufacturing	496.2973833	0.000903465	465.3980053	8436.02736	8.848544176
Use	1.799219899	1.23635E-06	6.117490904	14.80239753	0.014371027
Disposal	0.067912396	1.23313E-07	0.011823886	0.000471991	0.000471991

6.1.3. Interpretation

As it is shown in the above table, the phase with the highest footprint is the manufacturing phase. This makes sense because of the usage of resources and extraction of raw material as well as the usage of electricity and energy to build the product. More specifically, the most impact is seen on the resources, followed by the climate change, and the ecosystem. The numbers seem to be very high however for the small seeder, and this might be explained due to several uncertainties in the analysis, explained in the following section.

6.1.4. Data consideration

Unfortunately, this is only a preliminary study. Since the design team does not have full access to the Ecoinvent Software, they were only able to work with what was given to them by Mr. Alexandre Courchesne. There are different sources of uncertainty in this model. Chromium steel 18/8 at plant was used to model the material composing the seeder. It is considered as a mix of differently produced steels and hot rolling. Since it is produced in plant, it is assumed that process such as the extraction of iron core, the transport, the fuel extraction, etc., up to the production of the steel were already considered. The volume produced however in unknown in the Ecoinvent Database, making our calculations less accurate. Material such as rubber, representing the wheel of the implement were also not considered as no information was found on that in the Impact2002+ preprocessed spreadsheet. Data on the following information were also not available, thus not included in the inventory: the infrastructure used for the manufacturing of the seeder, the direct emissions

The use phase of this cycle was not calculated precisely. The inventory takes into account the diesel fuel consumption and the amount of agricultural machinery and of the shed, which has to be attributed to the planter. It is not mentioned how big the planter is, thus some uncertainties might arise there. Thus, the amount of emissions to the air from combustion and the emission to the soil from tyre abrasion during the work process might not be precise. Additionally, the following activities where considered part of the work process: preliminary work at the farm, like attaching the adequate machine to the tractor; transfer to field (with an assumed distance of 1 km); field work (for a parcel of land of 1 ha surface); transfer to farm and concluding work, like uncoupling the machine. The overlapping during the field work is also considered, however, the planting material, maize, is not taken into account. Not included in the study are dust other than from combustion and noise. It would have perhaps been easier to conduct the study on a drought animal, as this might be the most likely scenario in the small-scale farms of Rwanda. Finally, data on waste disposal are also estimated based on Western Europe's waste disposal of similar machinery. The one in the Ecoinvent database is however considered larger in size than our seeder, thus adding more uncertainty in the study.

6.2. Socio-cultural considerations

From a social perspective, several criteria are important to consider while designing the seeder. Most importantly, it is crucial for it to be user-friendly and require little maintenance, all while delivering efficient results that will help in the increase of productivity and yields. In fact, the average household family size in the SSA region is said to be five to six members (FAO, 2006). he same family members might have differing work potentials and some members might devote some effort to off-farm work. The mechanized seeder will therefore help reduce labour hours requirements for small-scale farmers, allowing them to have more leisure time, and therefore increasing their quality of life, or even have more free time to work elsewhere around the farm or on entirely separate activities. This will also reduce the power required for seeding by making the process of seeding more efficient. Additionally, women who generally do not have much physical capability to offer more than mechanical assistance will be able to play a bigger role on farms. This will also promote less injuries while conducting the laborious activity of cutting residues, prepping the row and opening them to prepare for the seeding operation. Thus, the farming effectiveness will lead to an increase in yields and directly contribute to a better lifestyle for the farmer's family and their lifestyle. A case study around 17 countries in Africa showed that farmers shifting from hand-hoes and other manual farm equipment to mechanized tools experienced a doubling in their area of cultivation (FAO, 2006). This proves that the adoption of mechanized tools on small-scale farms can lead to the expansion of the area of the land cultivated. Finally, the implementation of the mechanical seeder will contribute to the improvement of skills and teach farmers how to utilize technology on the farm and potentially raise labour wages. However, for this to work, it is crucial to educate the farmers on self-run farms and operational functioning of the seeder by implementing various educational programs and training in order to ease the transition for them.

Concerns that this project might raise are related to the lack of well-paid opportunities in rural areas, associated with low education levels, which might affect the income of workers that work on farms that do not belong to their families.

6.3. Risk Matrix

The risk assessment of a project constitutes an important step during the design of a product since it quantifies and defines the inherent risk of the system by considering the category of probability against the category of consequence severity. Risk factors can be evaluated at ranks from one to three, where one represents the least likely and least dangerous risk, and three represents the most likely and dangerous. To ensure that all risks are equally assessed, and that appropriate measures are taken into consideration for the full functionality of the seeder, the following risk factor matrix was generated with an appropriate framework delineating risk contributors and mitigation procedures.

Table 2. Risk Factor Matrix

Risk Factor	Risk Rank	Risk Contributor	Mitigation Procedure
Unsafe machine operation Heavy duty equipment (safety using the machine)	**3**	Incorrect use of controls	Ensure personnel are provided with, and read, operation manual for equipment Provide training
Smoke inhalation	**1**	Exhaust	Do not loiter around exhaust
On-site storage risks	**2**	Weather conditions	Ensure equipment is stored in a weather resistant enclosure
Manufacturing Risks (safety, tools, equipment, etc)	**1**		Abide by all standard WHMIS rules to ensure worker safety in the plant
Warehouse Risks (safety, weight, dangers)	**1**		Abide by all standard WHMIS rules to ensure worker safety in the warehouse

Transportation Risks	**2**	Standard dangers related to loading and unloading	Ensure that packaging is safe, as well as experience freight handlers are used
Excessive noise	**1**	Lawn mower sound	Ensure machine is well attached
Cutting, shearing injury	**3**	Sharp edges, disks	Keep hands, feet and clothing away from driven parts
Hazardous Materials	**2**	Gasoline, oil, lubrication	Ensure all hazardous materials are correctly labelled with bright and internationally accepted labelling standards.
Engine safety	**3**	Moving parts and combustion engine Power factor	Ensure instructions for engine upkeep, lubrication and treatments is provided
Maintenance Requirements	**2**	Farmers not having the required workforce/knowledge to do so themselves	Replacing engine oil, gas, cleaning - must be done to be safe, this is big risks if info is not clear to developing countries
Entanglement, drawing in, trapping	**3**	Rotating shafts, moving chains, belts	Safety guards, decal
Object striking the operator, enabling the seeder to function properly	**2**	Material discharge, soil residues	Installation of a furrow opener on the seeder

The four main risks to be considered in the seeder system are the engine safety, the unsafe use of the machine and the entanglement, drawing in, as well as cutting and searing injuries. Firstly, there is a considerable risk for the machine operators to use the controls incorrectly, leading to unsafe use of the machine. These circumstances result from the unfamiliarity that farmers may have towards mechanized machinery on small-scale farms because they are not commonly used. This risk will be mitigated by implementing training programs for users before the operation of the machine, as well as ensuring that only farmers who know how to employ the seeder do so. Further risks posed to machine operators involves injuries such as cutting or shearing, as well as entanglement and drawings. To reduce the likelihood of this risk, the user must keep their hands, feet and clothing away from moving parts. Finally, engine safety is yet another risk that can be alleviated by ensuring that instructions for engine upkeep, lubrication and treatments are provided.

6.4. Financial analysis

A financial analysis will be conducted to compare the different economic considerations in Canada as well as Rwanda. This will help the design team decide where to manufacture its seeder.

6.4.1. Economic considerations in Canada

Ensuring the economic viability of the mechanized seeder implemented in sub-Saharan African small-scale farmers is vital to the success of the project. The following financial analysis is proposed. This analysis includes a breakdown of all applicable, and quantifiable economic attributes of the design and is divided into three major economic subsections: *Investments and Costs (1.1), Cost-Benefit Breakdown (1.2), and Cost-Benefit Result (1.3).*

The following monetary dollar values include applicable taxes and are in Canadian Dollars (CAD). Values which were converted from United States Dollars (USD) were converted at a rate of **1.00 CAD = 0.75 USD** (TSX).

6.4.1.1. Investments and costs

Table 3, as seen below, contains the cost of each component used in the manufacturing of one unit. Each cost is final, including any additional fees that are associated with the component; this includes any delivery or handling charges. As of April 2020, the total stakeholder investment for the mechanized seeder is **$1395.08**.

Table 3. Cost breakdown in Canada (Source: Shoup Manufacturing, 2020).

UNIT	Quantity	Cost (CAD)	Working period (years)
Seed meter and seed delivery tube	1	$204.25	15
Furrow opener	1	$19.98	5
Residue cutter	1	$150	5
Seed hopper	1	$14.99	15
Overall-frame	1	$135.87	10
Sprockets and Chain	2	$6.88	3
Furrow closing wheel	2	$50	5
Labour*	2	$599.52	-
	SUBTOTAL	**$1181.49**	
	FREIGHT**	$60.00	
	HST***	$153.59	
	TOTAL	**$1395.08**	

*The price for labour was calculated assuming a minimum wage of $24.98 per hour, and estimating that the assembly of the parts will take a total of 12 hours. The minimum wage is the standard salary paid in Canada.
**This varies based on purchaser location. $60 is the estimate for international shipping for a company, from Canada to Africa, using standard USPS shipping channels.
***The price for all purposes will be treated as the **SUBTOTAL amount, $1181.49**, as HST does not apply to all company expenses for manufacturing of goods. The HST amount is paid to the vendors, and later claimed and reimbursed.

Note: The total price of building the prototype increased by $99.41 from the price presented in the previous report as the initial design was altered and some components of the seeder were replaced. This decrease is however not noticeable since labour costs to build the machine were added in this report, explaining the increase in price.

6.4.1.1.1. Depreciation analysis

Agricultural Machinery Dep. Government Standard; South Africa = 40% in year 1, and 20% of the current value per year for the following three years [declining balance]

Sample calculation - Depreciation by Declining Balanced; CV = PV*(1 - R)
CV = current value ; PV = purchase value ; R = depreciation rate at purchase year

Salvage value is the estimated resale value of an asset at the end of its useful life or the minimum value of an asset-based on non-depreciating components. In the case of this design, the mechanized seeder has several metal components, which can be scrapped for the value of the metal. Depreciation analysis will be done on a 5-year time frame for the purpose of this report. Given resource values as of 2019-03-10, the estimated salvage value of this mechanical seeder is $290.36.

Table 4. Depreciation table over a 5 year period in Canada.

Year	Current Value at Date	Depreciated Amount to Date	Percentage Loss to Date
0	**$1181.49**	$0.00	0.0%
1	$708.89	$472.596	40.0%
2	$567.12	$614.3748	52%
3	$453.69	$727.797	61.6%
4	$362.95	$818.5363	69.3%
5	**$290.36**	$891.127	75.4%

6.4.1.1.2. Life cycle cost analysis in Canada

The life cycle cost analysis illustrates the total expense to the purchaser assuming each component of the design is replaced after it's estimated useful lifetime has expired. Simply put, if the farmer continues to maintain the seeder, this analysis depicts the estimated cost of replacing the components required for the seeder to continue functioning over a 10-year period. The time period was limited to 10 years, representing the economic lifetime of the design. After 10 years it is recommended that the purchaser investigate new technology and seeders.

Table 5. Life Cycle Cost of Mechanized seeder in Canada

Time frame	Component(s) to be replaced	Replacement costs	Total Replacement costs to date	Total cost paid including purchase price
Year 0	None	$0.00	$0.00	**$1181.49**
Years 1 to 2	None	$0.00	$0.00	$1181.49
Year 3	Sprockets and chains	$6.88	$6.88	$1188.37
Year 4	None	$0.00	$6.88	$1188.37
Year 5	Furrow opener Residue cutter Furrow closing wheel	$219.98	$226.86	$1408.35
Years 6 to 9	None	$0.00	$226.86	$1408.35
Year 10	Overall frame	$135.87	**$362.73**	**$1544.22**

From the table above, it is concluded that to maintain the seeder for 10 years it will cost the purchaser $362.73. Including the purchase price, this design has a total 10-year-cost of $1544.22 CAD.

6.4.1.2. Cost benefit breakdown in Canada

Farm power is vitally important to small farms assets. It improves labour productivity and has the benefit of allowing family labour to be engaged in other income-earning tasks, whether agricultural or not. A shortage of power in a farm constrains the increases in agricultural productivity and may result in the stagnation of the farm’s family income, with a danger of sliding towards poverty and hunger. However, for mechanization to be successfully implemented in small-scale farms, it must contribute to an improvement in profitability and generate adequate returns in order to justify the investments. Since small-scale farms usually do not hire employees, they save labour costs. Precision farming, however, does save the farmers time, as the labour required to conduct seeding operation of maize manually is 80 hours per hectare and 400 hours per hectare to prepare the land before placing the seeds (van Hemst, 1986).

Sample calculation - Assuming a farmer produces $400 per month
($\$400/month$) × ($80 + 400\ hours/hectare$) × ($1\ month$ / $730\ hours$)
AMOUNT SAVED IN TIME VALUE = $263.01 per hectare

The amount saved in time value, calculated above, does not only save the farmer time and labour for the seeding operation, but also saves them time in terms of land preparation and opening of the furrow, as well as a seed covering.

Assuming that a small-scale farm of 0.47 hectares produces corn twice per year, with a price of corn at $160 per metric ton; 10.9 metric tons per hectare of corn is produced. This comes up to $1636.39 USD per year or **$2177.22 CAD**, which represents the farmer's income before costs, ie., not including seed price, materials, and equipment.

6.4.1.3. Cost benefit results

In this section, the Net Present Value (NPV), the Payback Period (PP) and the Internal Rate of Return (ROI) are calculated and briefly analyzed to ensure the fiscal validity of the project. All calculations seen below are based on a farm of one hectare in area. The NPV, the payback period, and the return on investment would decrease proportionately with any increase in farm area as the equipment investment would remain the same, however, labour and time savings would increase. Additionally, the calculations were done over a 5-year period, assuming a cost of capital of 4% which represents the current cost of capital of the Royal Bank of Canada business lawn. The fuel price was neglected due to minimal fuel usage and variable prices especially in the African region, however if they were, they are expected to be around $50 per year.

$\boldsymbol{NPV}$ = ($B0 - C0/ (1 + i)$^0) + ($B1 - C1/ (1 + i)$^ 1)+. . . +($Bn - Cn$ /(1 + i) ^n)
$\boldsymbol{NPV}$ = $110.25 (>>0, thus this project is deemed very lucrative over a 10-year period)
$\boldsymbol{Payback\ Period}$ = ($Cost - salvage\ value$) / ($savings\ per\ year$)
$\boldsymbol{Payback\ period}$ = (1181.49 – 290.36) / **263.01** = **3.4 $\boldsymbol{years}$ (**This indicates that all costs will be recovered in 3.4 years)
$\boldsymbol{IRR}$ = **7.042%** (normally anything above the cost of capital, 4% in this case, is deemed acceptable. This IIR is *very* high, once again confirming the fiscal success of this design.)

This is a strong return on investment for the purchaser of the product as it is significantly above the cost of capital.

6.4.2. Economic considerations in Rwanda

6.4.2.1. Investments and costs

No data for the costs of each component used in the manufacturing of one unit in Rwanda was available online. The design team first reverted to contacting Mr. Charles Bucago from the Ministry of Agriculture in Rwanda. Despite several attempts, no answer was given. The team then tried to look at other markets such as the Indian Agricultural Market and estimate the prices for each part in Rwandan franc (FRw). A few challenges were faced while conducting this method; parts such as the seed meter and its seed delivery tube, as well as the residue cutter were not found. The prices had to be estimated comparing it to the Canadian prices. Overall, the total cost, including delivery and handling charges were summed to **299545.13 FRw**, **or $451.63 CAD.** This total cost is final and includes delivery or handling charges, as of April 2020.

Table 6. Cost breakdown in Rwanda *(Source: IndiaMART, 2020)*.

UNIT	Quantity	Cost (FRw)	Working period (years)
Seed meter and seed delivery tube	1	81080.53	15
Furrow opener	1	99171.78	5
Residue cutter	1	4088.16	5
Seed hopper	1	40540.26	15
Overall-frame	1	23648.49	10
Sprockets and Chain	2	3718.94	3
Furrow closing wheel	2	47296.97	5
Labour	2	2616.42	-
	TOTAL	**299545.13**	

The design team was however still not pleased by the price that was calculated and reverted to another approach. Generally, the price of materials does not fluctuate around the world. It is the price of labour that makes a difference in the manufacturing of a product. This pushes companies to manufacture their goods in developing countries.

In fact, it costs $1181.49 CAD to build the small-scale agricultural seeder prototype in Canada. This includes the labour job involved in building the parts as well. The minimum wage for this work in Canada is $24.98 per hour, whereas the minimum wage in Rwanda for the same amount of work is $3 per hour, which shows that labour costs are 83% higher in Canada than in Rwanda. Following this logic, the price for building the spare parts as well as assembling them in Rwanda will be around **$200.85**.

6.4.2.1.1. Depreciation analysis

Agricultural Machinery Dep. Government Standard; South Africa = 40% in year 1, and 20% of the current value per year for the following three years [declining balance]

Sample calculation - Depreciation by Declining Balanced; CV = PV*(1 - R)

CV = current value ; PV = purchase value ; R = depreciation rate at purchase year

Salvage value is the estimated resale value of an asset at the end of its useful life or the minimum value of an asset-based on non-depreciating components. In the case of this design, the mechanized seeder has several metal components, which can be scrapped for the value of the metal. Depreciation analysis will be done on a 5-year time frame for the purpose of this report. Given resource values as of 2019-03-10, the estimated salvage value of this mechanical seeder is **$49.3608**.

Table 7. Depreciation table over a 5 year period in Rwanda.

Year	Current Value at Date	Depreciated Amount to Date	Percentage Loss to Date
0	$200.85	$0.00	0.0%
1	$120.51	$80.34	40.0%
2	$96.408	$104.442	52.0%
3	$77.126	$123.724	61.6%
4	$61.70112	$139.148	69.28%
5	**$49.3608**	$151.48	75.4%

The salvage value is low in this case. However, since its initial price is low compared to the products found in the market, farmers would be more encouraged to buy this product than other ones. Additionally, when this prototype is commercialized, its manufacturing price will decrease drastically which will make its price on the market lower.

6.4.2.1.2. Life cycle cost analysis in Rwanda

The life cycle cost analysis illustrates the total expense to the purchaser assuming each component of the design is replaced after it's estimated useful lifetime has expired. Simply put, if the farmer continues to maintain the seeder, this analysis depicts the estimated cost of replacing the components required for the seeder to continue functioning over a 10-year period. The time period was limited to 10 years, representing the economic lifetime of the design. After 10 years it is recommended that the purchaser investigate new technology and seeders.

Table 8. Life Cycle Cost of Mechanized seeder in Rwanda.

Time frame	Component(s) to be replaced	Replacement costs	Total Replacement costs to date	Total cost paid including purchase price
Year 0	None	$0.00	$0.00	**$200.85**
Years 1 to 2	None	$0.00	$0.00	$200.85
Year 3	Sprockets and chains	$5.61	$5.61	$206.46
Year 4	None	$0.00	$5.61	$206.46
Year 5	Furrow opener Residue cutter Furrow closing wheel	$227.00	$232.61	$433.46
Years 6 to 9	None	$0.00	$0.00	$433.46
Year 10	Overall frame	$35.66	$268.27	**$469.12**

From the table above, it is concluded that to maintain the seeder for 10 years it will cost the purchaser $268.27 CAD. Including the purchase price, this design has a total 10-year-cost of $469.12 CAD, which is way lower than the 10-year-cost of the prototype built in Canada with $1544.22 CAD.

6.4.2.2. Cost benefit breakdown in Rwanda

The Cost-Benefit breakdown is the same for this prototype as the one presented above.

6.4.2.3. Cost benefit results

In this section, the Net Present Value (NPV), the Payback Period (PP) and the Internal Rate of Return (ROI) are calculated and briefly analyzed to ensure the fiscal validity of the project. All calculations seen below are based on a farm of one hectare in area. The NPV, the payback period, and the return on investment would decrease proportionately with any increase in farm area as the equipment investment would remain the same, however, labour and time savings would increase.

Additionally, the calculations were done over a 10-year period, assuming a cost of capital of 4% which represents the current cost of capital of the Royal Bank of Canada business lawn. The fuel price was neglected due to minimal fuel usage and variable prices especially in the African region, however if they were, they are expected to be around $50 per year.

$\boldsymbol{NPV} = (B0 - C0/(1+i)^{0}) + (B1 - C1/(1+i)^{1}) + \ldots + (Bn - Cn/(1+i)^{n})$
$\boldsymbol{NPV}$ = **$778.46** (>> 0)
$\boldsymbol{Payback\ Period} = (Cost - salvage\ value) / (savings\ per\ year)$
$\boldsymbol{Payback\ period}$ = (200.85 – 35.66) / **263.01** = 0.63 years **(**This indicates that all costs will be recovered in 0.63 years)
$\boldsymbol{IRR}$ = 128**%**

The NPV for the prototype produced in Rwanda is bigger than the NPV of the prototype used in Canada, thus production should take place in Rwanda.

7. Conclusion

This report introduces a new developed mechanized seeder; an efficient upgrade in current technology used in Sub-Saharan Africa that should be adapted by smallholder farmers. Soil mechanics, agronomic requirements for crop establishment, seeder functional and operational requirements, field efficiency, climatic data, and many other factors were taken into consideration while designing the initial seeder. The Gaspardo seeder was disassembled to more closely fit the preliminary design. The seeder was modelled in SOLIDWORKS, mechanical analysis was conducted and verified in ANSYS to determine restrictions to any new seed meter that may be attached. It was determined that the biggest environmental footprint was in the manufacturing process. Additionally, it is most economical to produce it in Rwanda. For future work, it is recommended to determine mechanical stresses on other components of the seeder, such as the furrow opener, test the seeder in soil, modifying the design as necessary, and simulate soil machine interaction using specialized software. Overall, although the project was not seen to completion due to the COVID-19 outbreak, it was a great learning experience for the team.

8. Acknowledgements

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Appendices

Appendix A – Pugh charts from BREE 490 preliminary design

Table 1. Pugh chart for residue cutting device.

RESIDUE CUTTING DEVICE		Plain Disc Coulter	**Notched Disc Coulter**	Bubble Disc Coulter	Ripple Disc Coulter	Wavee Disc Coulter	Turbo Disc Coulter
Criteria	**Weight**						
Cut residue and displace sideways	**3**	0	**1**	0	1	0	0
Penetrate hard soil; mild disturbance	**2**	1	**1**	0	1	0	0
Minimal seedbed disturbance	**1**	0	**0**	-1	0	0	0
	TOTAL	**2**	**5 (good for high residue and hard soils)**	**-1**	**5**	**0**	**0**

Table 2. Pugh chart for furrow opening device.

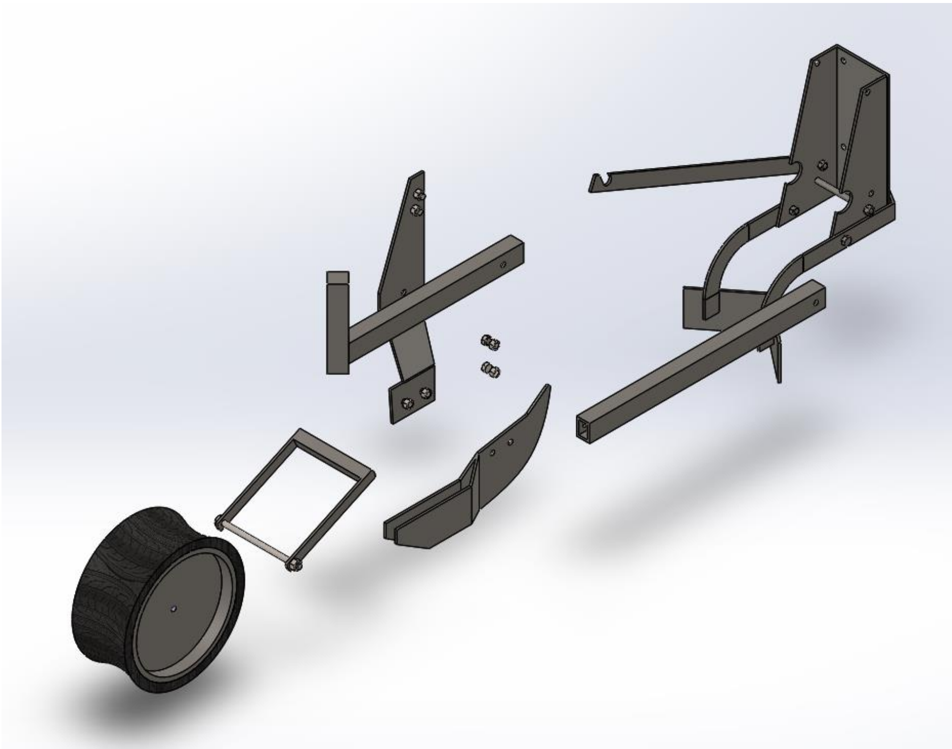
FURROW OPENER		**Concave Disc**	Bioblade	Disc Coulter	Powered	Tine Type	Runner Type
Criteria	Weight						(Not good for clay)
Minimal seedbed disturbance	**2**	**0**	1	0	0	0	0
Maintain uniform depth	**2**	**1**	1	1	0	-1	-1

Minimal compaction of furrow walls	**2**	**0**	0	0	1	1	-1
Soil flow in furrow after not before seed placement	**1**	**1**	0	1	0	0	0
Adjustability	**1**	**0**	0	0	0	-1	0
Conducive to seed delivery	**2**	**1**	1	1	1	0	1
Minimal vertical force	**2**	**-1**	-1	0	0	0	0
Durability	**2**	**0**	0	-1	0	1	-1
Low cost	**2**	**0**	-1	0	-1	0	
	TOTAL	**3**	1	3	2	1	-3

Table 3. Pugh chart for seed covering device.

SEED COVERING		**Chain**	Concave Disc	Finger	Knife	Paddle	Tine	**Disc Coulter**	Finger Wheel Type
Criteria	Weight								
Regulate depth of soil cover	**1**	**0**	0	0	0	0	0	**0**	0
Relevel seedbed	**1**	**1**	1	1	1	1	1	**1**	1
Minimal disturbance to seed or seedbed	**2**	**0**	0	0	0	0	-1	**0**	0
Adjustability	**2**	**1**	1	0	1	1	0	**1**	1
Hard soil, high residue	**2**	**0**	1	-1	-1	-1	-1	**1**	1
Simplicity	**2**	**1**	0	0	1	1	1	**0**	0
	TOTAL	**5**	**5**	**-1**	**3**	**3**	**0**	**5**	**5**

Appendix B – SOLIDWORKS models of Gaspardo seeder



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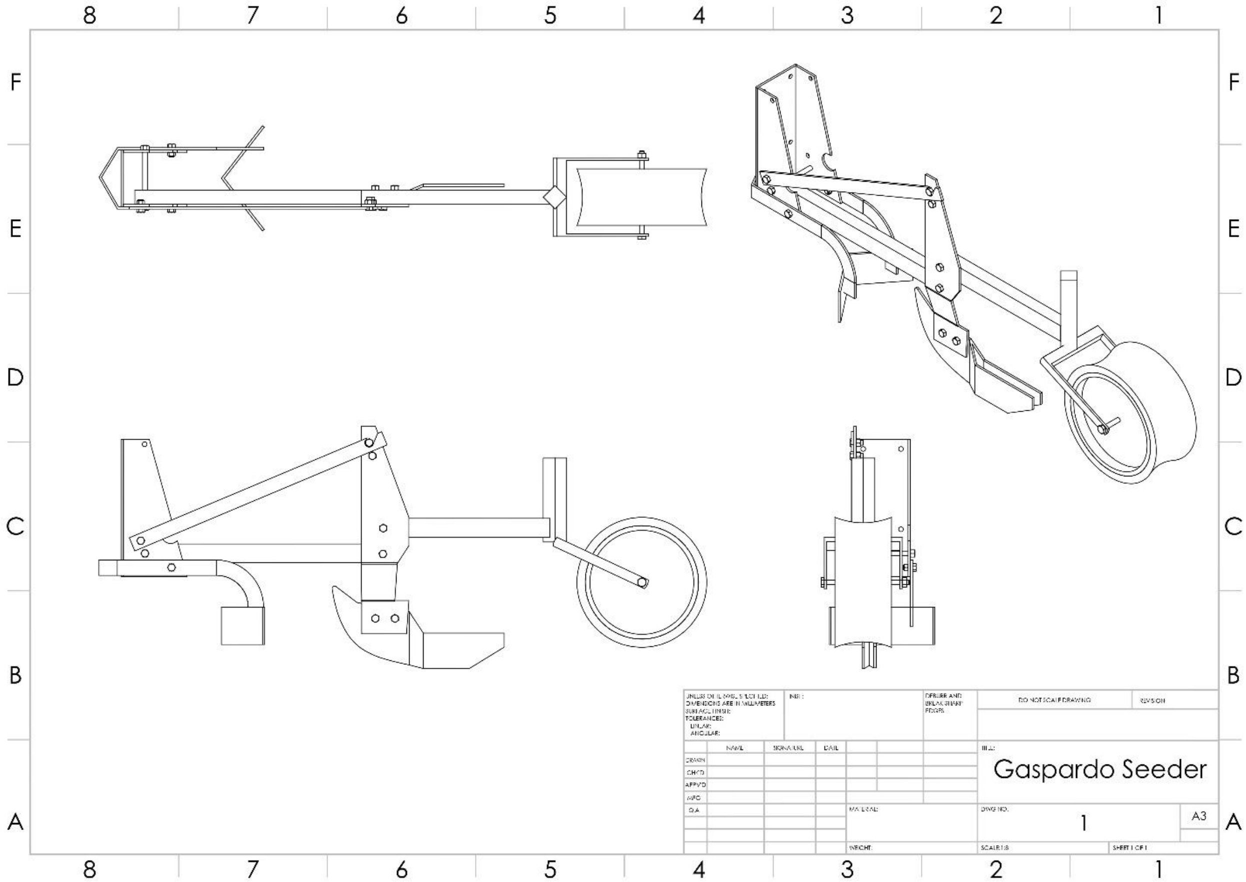
Gaspardo Seeder
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REVISION
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1
A3
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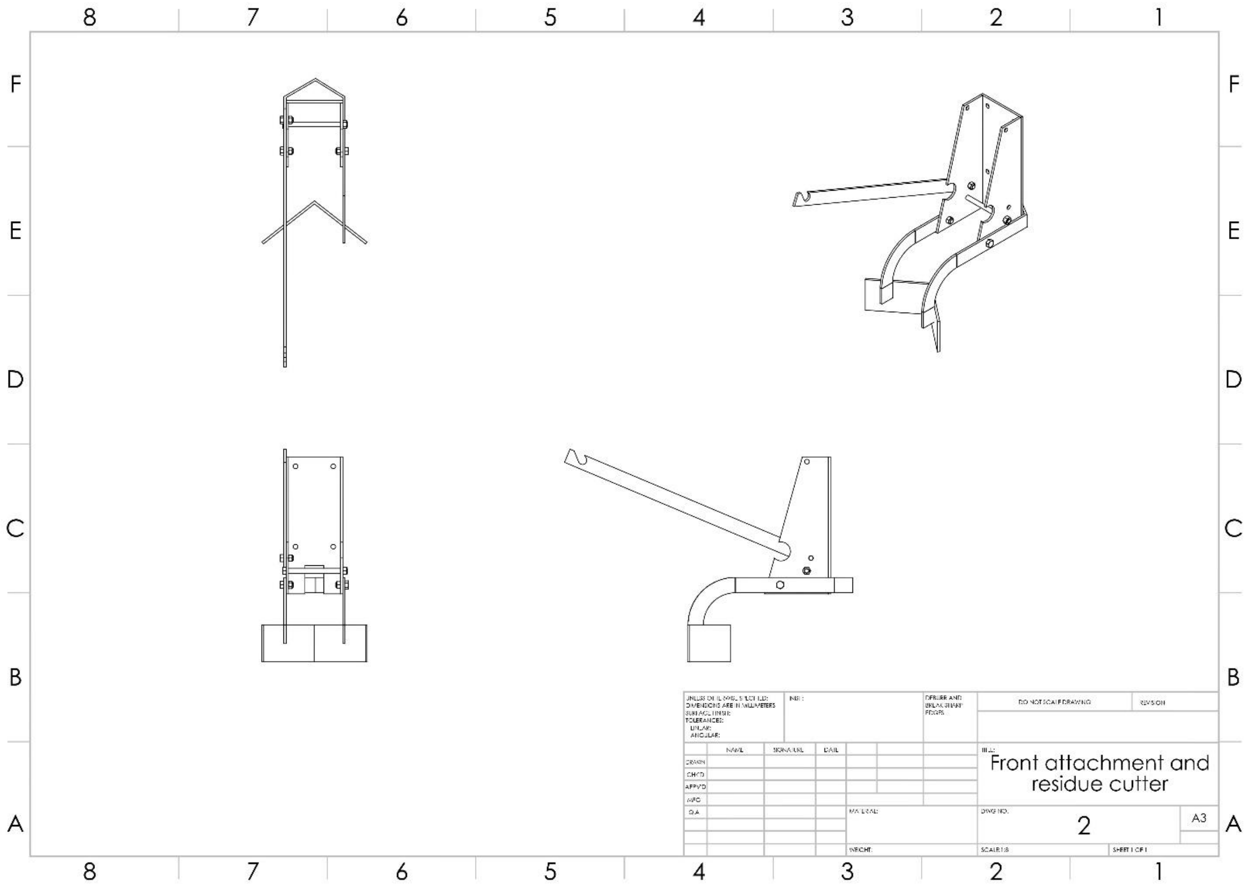
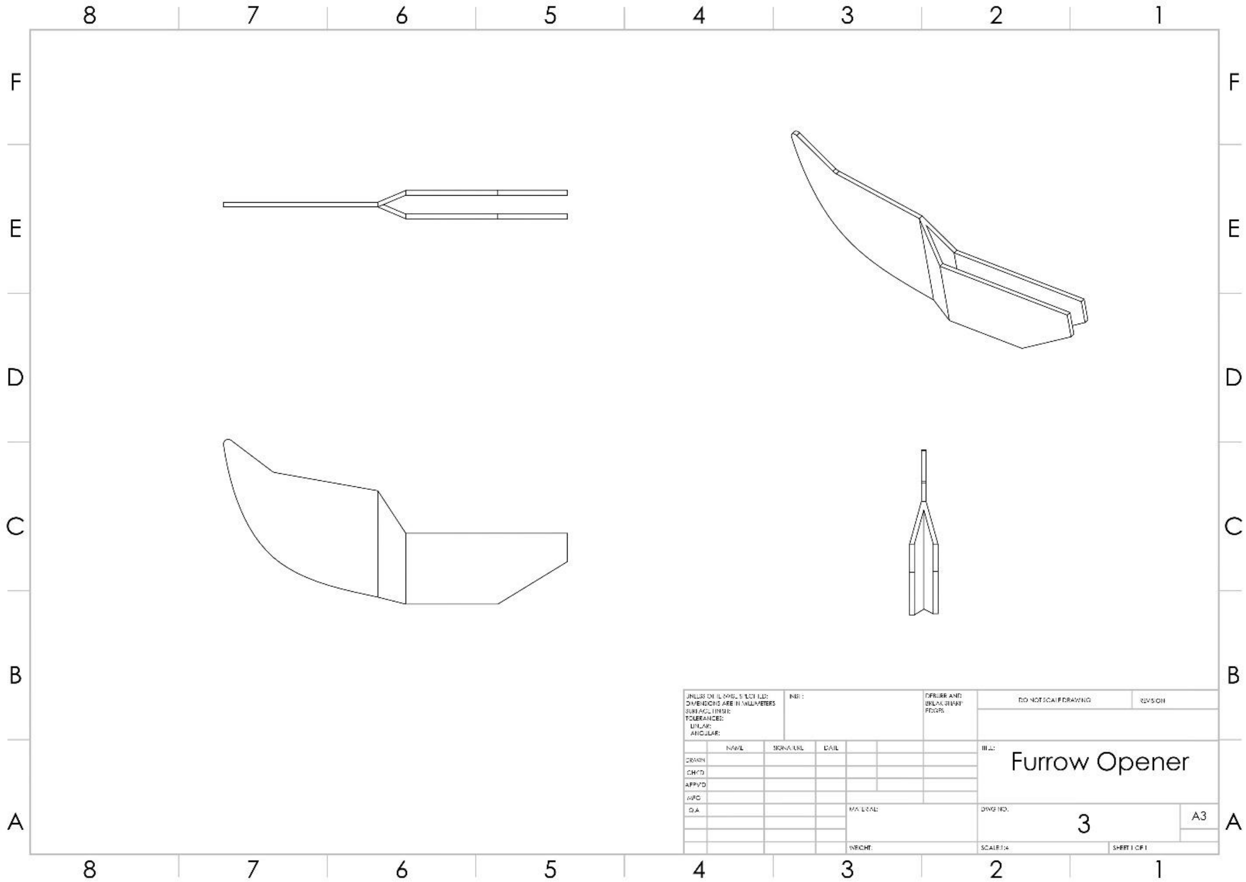
DIMENSIONS ARE IN MILLIMETERS
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
SCALE:1:8
SHEET 1 OF 1



Front attachment and residue cutter
2
A3


Furrow Opener
DWG NO.
3
A3
DO NOT SCALE DRAWING
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
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SIGNATURE
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WEIGHT:
TITLE:
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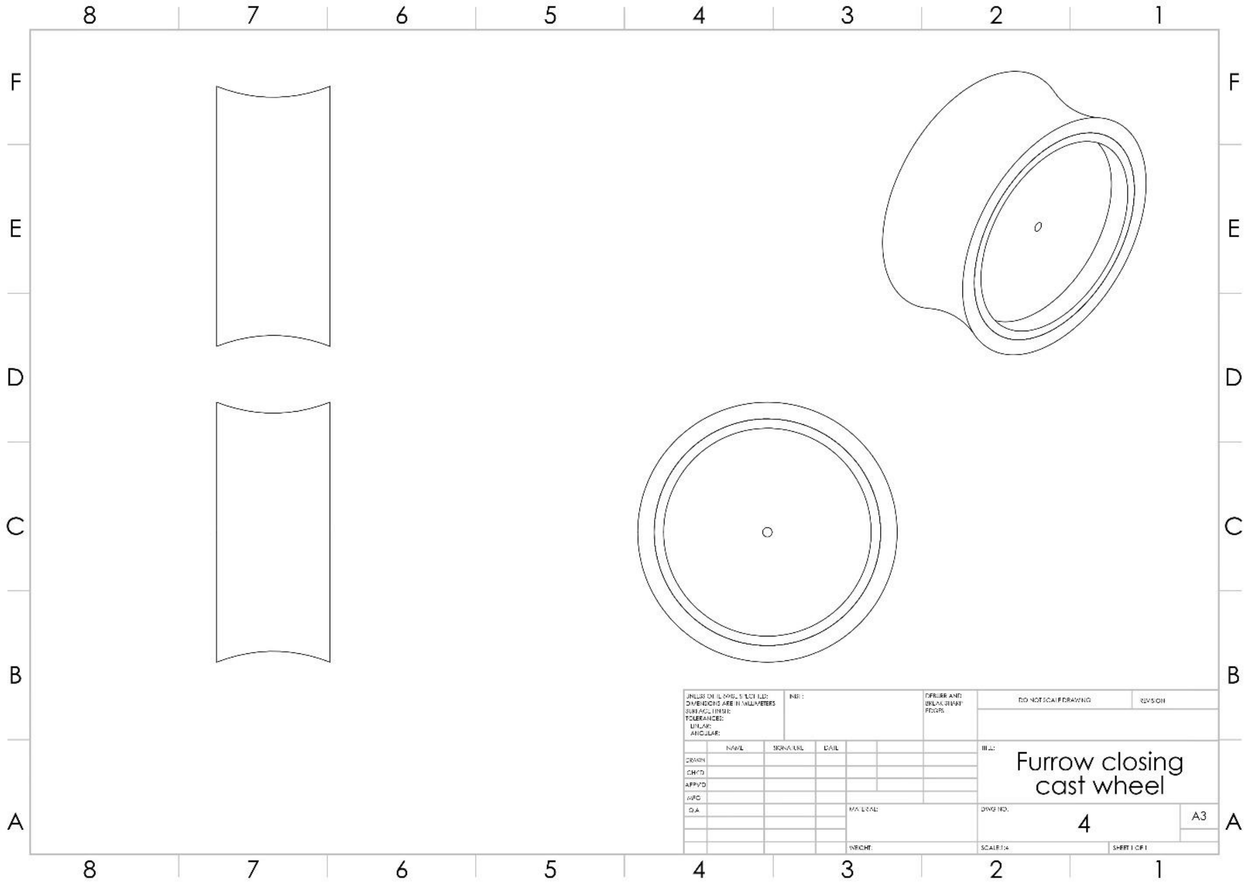
SHEET 1 OF 1



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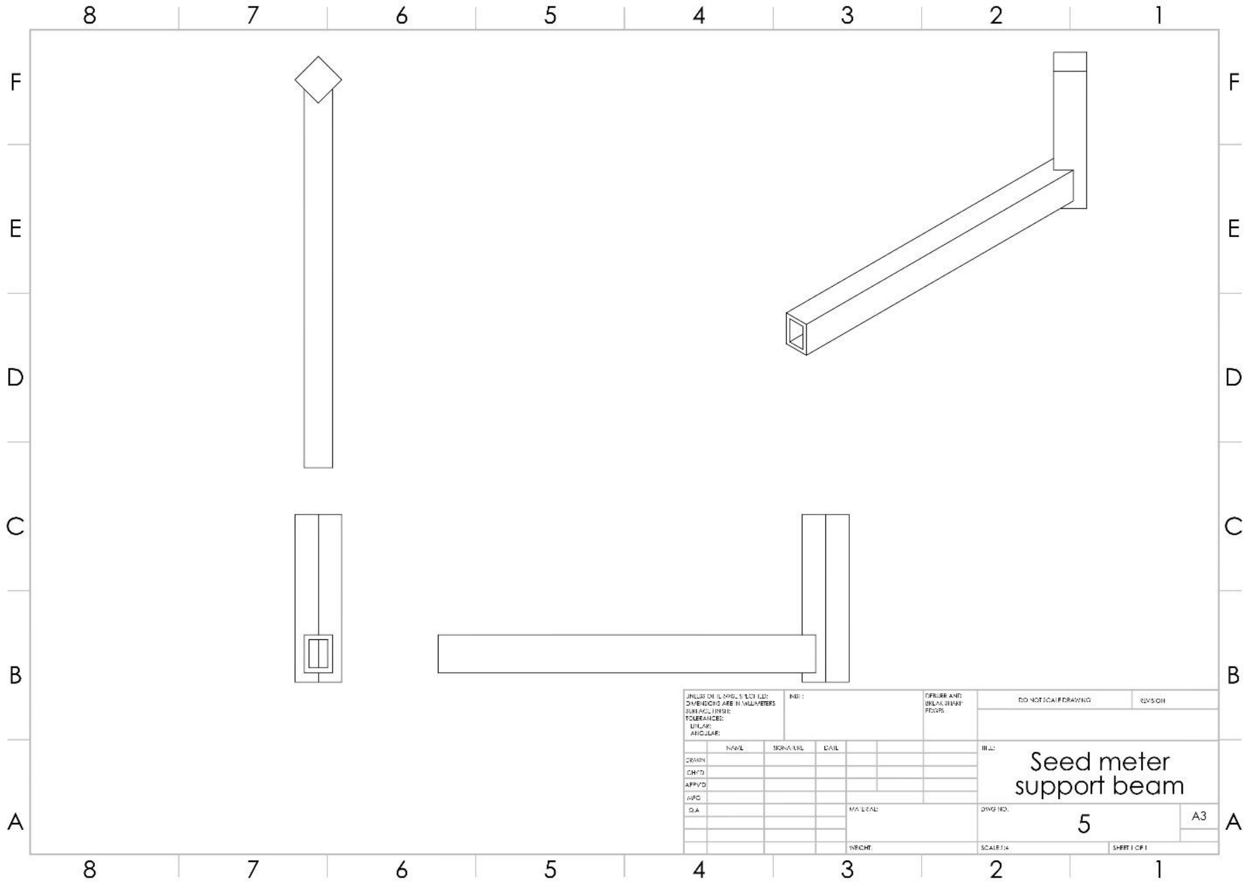
WEIGHT:
Furrow closing
cast wheel
DWG NO.
4
A3
SHEET 1 OF 1

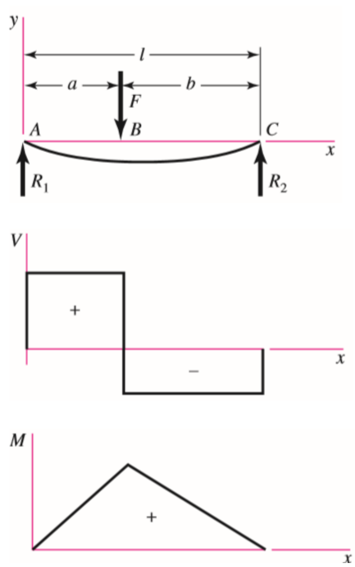


Seed meter support beam
5
A3

Appendix C – Mechanical analysis calculations

Mechanical analysis was conducted to determine the load that could be carried by the beam holding the seed meter. It was assumed that the beam was only subject to bending stress, shear stress was considered negligible. It was assumed to be simply supported with an intermediate load (Fig. 1).

6 Simple supports—intermediate load



$$R_1 = \frac{Fb}{l} \qquad R_2 = \frac{Fa}{l}$$

$$V_{AB} = R_1 \qquad V_{BC} = -R_2$$

$$M_{AB} = \frac{Fbx}{l} \qquad M_{BC} = \frac{Fa}{l}(l - x)$$

$$y_{AB} = \frac{Fbx}{6EIl}(x^2 + b^2 - l^2)$$

$$y_{BC} = \frac{Fa(l - x)}{6EIl}(x^2 + a^2 - 2lx)$$

Figure 1. Shear, moments, and deflection of a simply supported beam subject to intermediate load. (Source: Budynas & Nisbett, 2011).

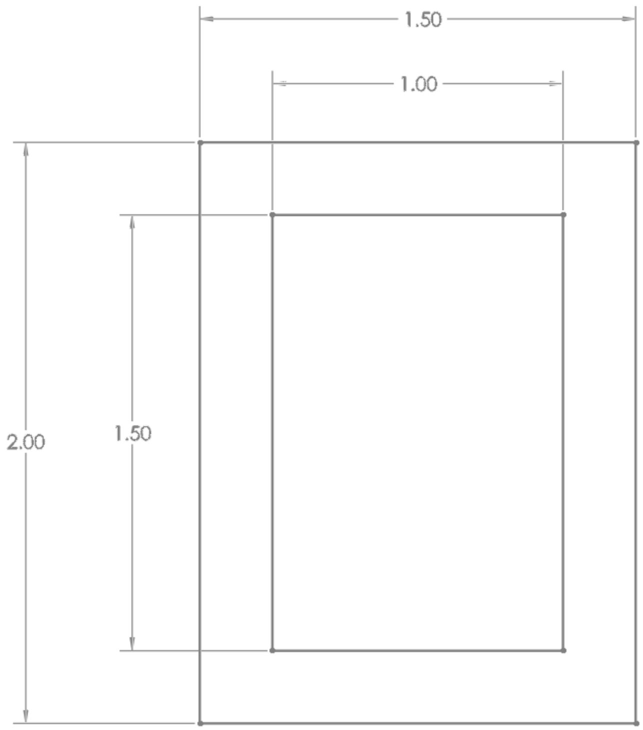
Based on Figure 1 definitions of the seed meter beam:

$$a = 6\ inches = 0.1524\ m$$

$$b = 14\ inches = 0.3556\ m$$

$$l = 20\ inches = 0.508\ m$$

The cross-section properties are as follows:



where

$$B = 1.5\ inches = 0.0381\ m$$

$$H = 2\ inches = 0.0508\ m$$

$$b = 1\ inch = 0.0254\ m$$

$$h = 1.5\ inches = 0.0381\ m$$

Thus the moment of inertia is:

$$I_x = \frac{BH^3}{12} - \frac{bh^3}{12}$$

$$I_x = \frac{(0.0381)(0.0508)^3}{12} - \frac{(0.0254)(0.0381)^3}{12}$$

$$\boldsymbol{I_x = 2.992 \times 10^{-7} m^4}$$

And distance to neutral axis:

$$c = \frac{1}{2}H$$

$$c = \frac{1}{2}(0.0508)$$

$$\boldsymbol{c = 0.0254}$$

Material properties are assumed based on ASTM A36 steel: $\boldsymbol{\sigma_{\max} = 250\ MPa}$

Using the equation for maximum bending stress:

$$\sigma_{\max} = -\frac{Mc}{I}$$

where M is defined from Figure 1:

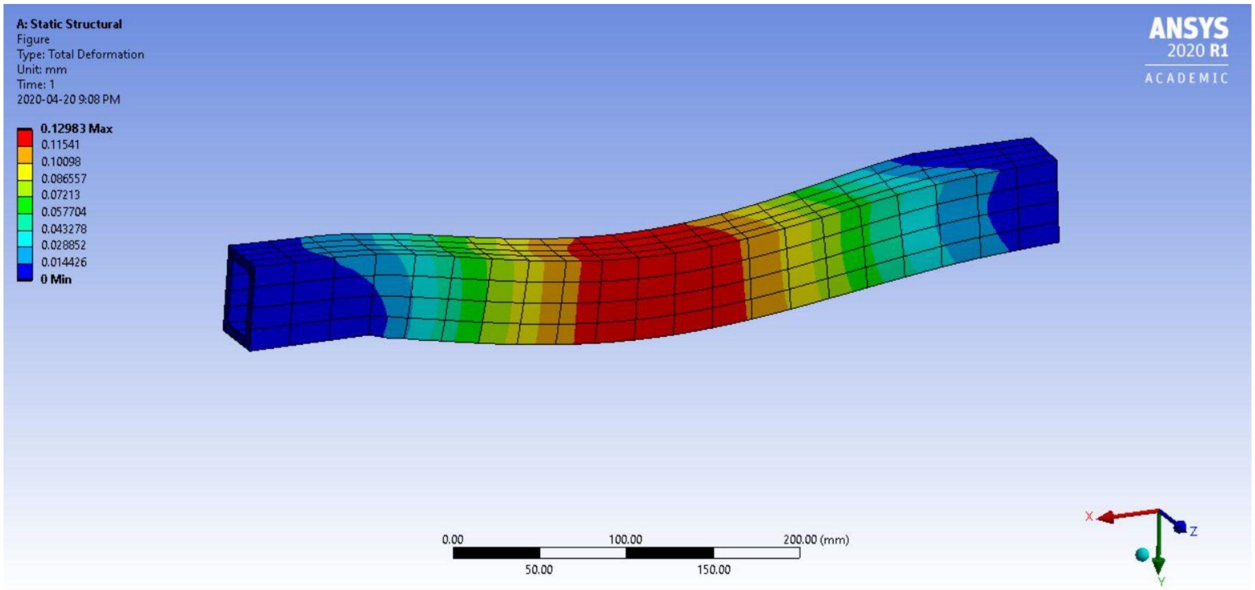
$$M = \frac{Fbx}{l}$$

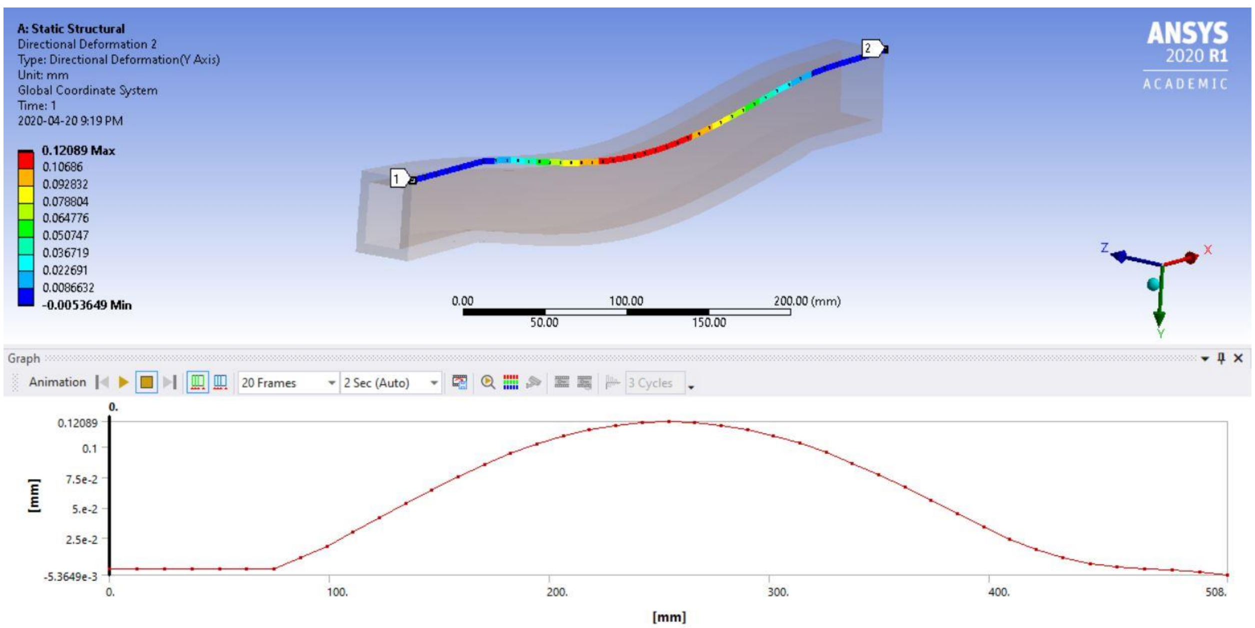
$$\sigma_{\max} = -\frac{M(0.0254)}{2.992 \times 10^{-7}}$$

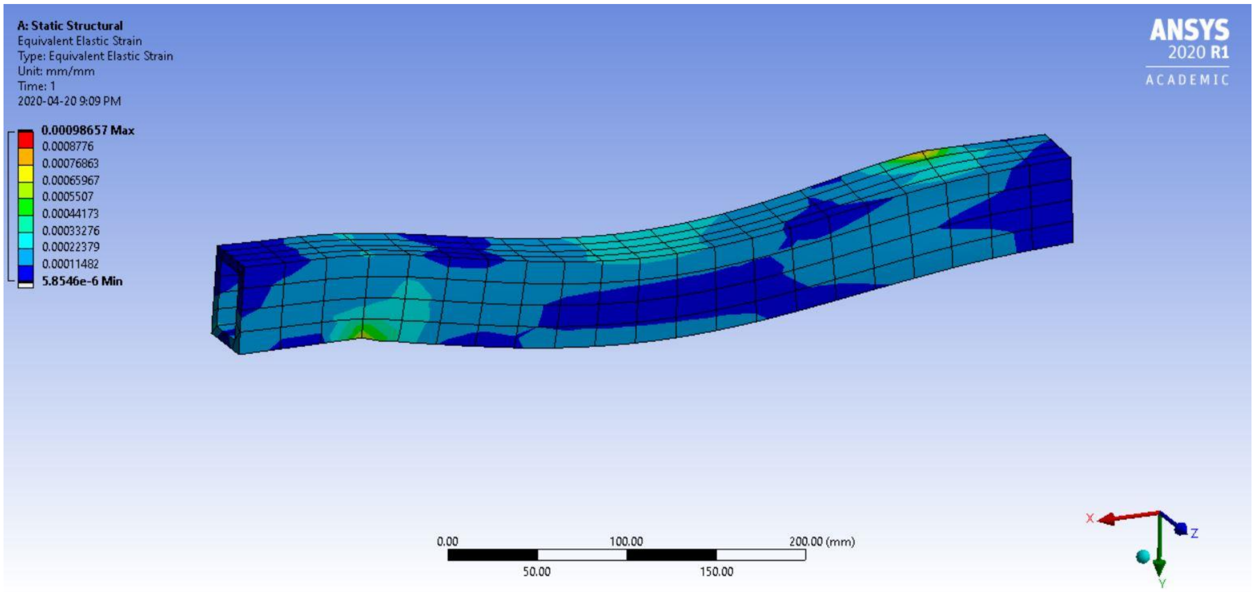
$$250\ MPa = (84902.6)\left(\frac{F(0.3556)(0.1524)}{0.508}\right)$$

$$\boldsymbol{F = 27601.71\ N}$$

Appendix D – ANSYS simulation results



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Equivalent Elastic Strain
Type: Equivalent Elastic Strain
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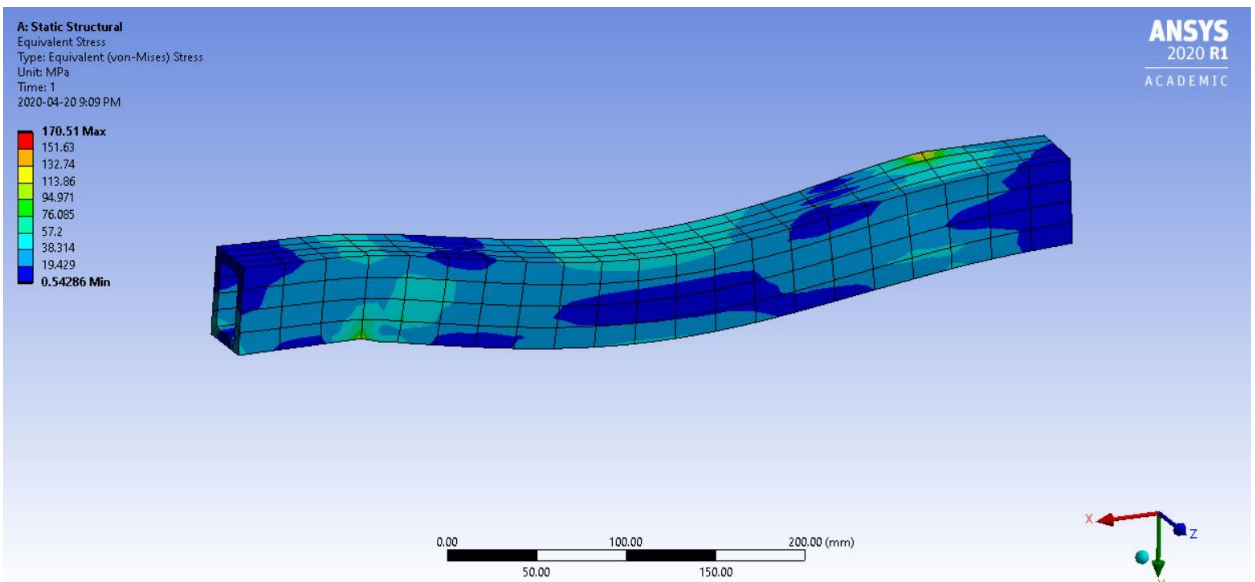
2020-04-20 9:09 PM
0.00098657 Max
0.0008776
0.00076863
0.00065967
0.0005507
0.00044173
0.00033276
0.00022379
0.00011482
5.8546e-6 Min
ANSYS
2020 R1
ACADEMIC
0.00
100.00
200.00 (mm)
50.00
150.00
X
Y
Z


A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
2020-04-20 9:09 PM
170.51 Max
151.63
132.74
113.86
94.971
76.085
57.2
38.314
19.429
0.54286 Min
ANSYS
2020 R1
ACADEMIC
0.00
100.00
200.00 (mm)
50.00
150.00
X
Y
Z

Appendix E – Soil calculations

Wheel slippage (Source: Walter, 2013)

$$wheel\ slippage\ \% = \frac{(Number\ of\ turns\ loaded - Number\ of\ turns\ unloaded) * 100}{number\ of\ turns\ unloaded}$$

Assuming the following:

Number of wheel revolutions loaded = 10

Number of wheel revolutions unloaded = 9

$$wheel\ slippage = \frac{(10-9) * 100}{9} = 11\%$$

Tractor performance can be calculated by summing wheel performances. Maximum TE is obtained with slip ranges of (Coates, 2002):

4-8% for concrete;

8-10% for firm soil;

11-13% for tilled soil;

14-16% for soft soils and sands.

Assuming during planting time, the soil will be tilled. The slippage obtained above is in the range of 11-13% for tilled soil.

Field efficiency (Source: Condra et al., 2017)

speed of row crop planter = 6.5km/h = 1.805m/s

row spacing = 0.508m

number of rows = 2 (farmers are able to add more on the machine)

Turning, adjusting the planter, adding seeds and other losses account for 10 %

The average width of cut to be 0.15m less than the machine working width

Area covered = 1ha = 10000m^2

$$Field\ efficiency\ (\%)\ = \frac{Effective\ field\ capacity(EFC)}{Theoretical\ field\ capacity(TFC)} * 100$$

$$TFC(ha/h) = \frac{travel\ speed\ \left(\frac{km}{hr}\right) * machine\ working\ width\ (m)}{10}$$

$$machine\ working\ width\ (m) = row\ spacing * number\ of\ rows$$

$$machine\ working\ width\ (m) = 0.508m * 2 = 1.016m$$

$$TFC = \frac{6.5 * 1.016}{10} = 0.66\frac{ha}{h}$$

$$Effective\ width\ \ of\ combine(m) = 1.016\ m - 0.15m = \ 0.866m$$

$$Time\ taken\ to\ cover\ 1ha\ (s) = \frac{Area\ covered}{new\ width * speed}$$

$$Time\ taken\ to\ cover\ 1ha\ (s) = \frac{10000}{0.866 * 1.805} = 6395.45s$$

$$Time\ lost = \ 10\% * \ time\ taken\ to\ cover\ 1ha = 12.5\% * 6395.45 = 767.45s$$

$$Total\ time\ (h) = \frac{time\ lost + time\ taken\ to\ cover\ 1ha}{3600} = \ 1.99h$$

$$EFC\ (ha/h) = \frac{Actual\ area\ covered}{total\ time}$$

$$Effective\ field\ capacity\ \left(\frac{ha}{h}\right) = \frac{1ha}{1.99h} = \ 0.502ha/h$$

$$Field\ effeciency\ \left(\frac{ha}{h}\right) = \frac{0.502}{0.66} * 100 = \ 76\%$$

Draft power ((Raghavan, Alvo & McKyes, 1990))

$$DI = Fi\ (A + Bv + Cv^2)wd$$

$$Pdb = \frac{DI\ v}{3.6}$$

DI = implement draft (N)

Pdb= drawbar power, kW (However, tractors are rated by brake power or net flywheel power rather than drawback power)

From the table

Fi = dimensionless texture adjusted factor = 1.0.

i = 1 for fine, 2 for medium, 3 for coarse textured soils (medium for this paper). F for medium= 1.0

A = 500, B=0.0, and C=0.0 for row planter for seeding only.

d = tillage depth, cm (1.0 is used for seeders)

w = rows for seeder

v=travel speed = 6.5km/h

$$DI = 1.0\ (500 + 0.0 * 6.5 + 0.0 * 6.5\text{^}2)\ 2 * 1 = \ 500N$$

$$Pdb = \frac{500 * 6.5}{3.6} = \ 0.903kW$$

Assuming the soil ahead of the disk and under the tractor is tilled, the ratio between drawbar and flywheel power is 0.73.

$$Equivalent\ power = \frac{0.903}{0.73} = 1.24\ kW$$

Appendix F – Preliminary GANTT Chart

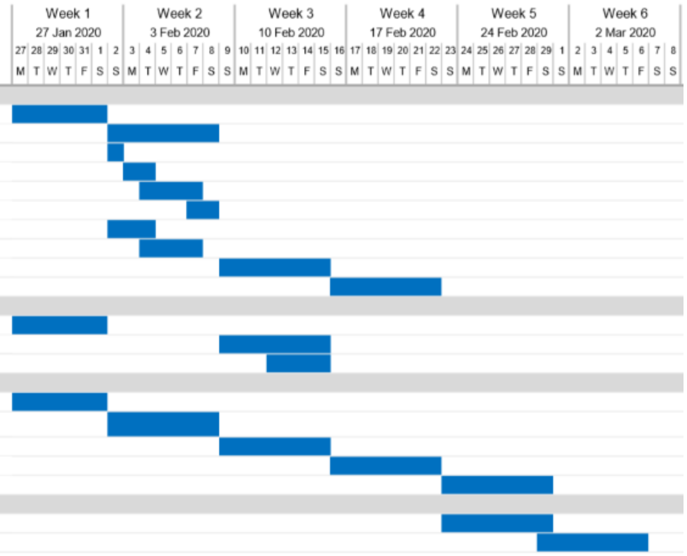
Design 3 Project Schedule

[Sree Ange Leen]

Project Start Date: 1-29-2020 (Wednesday) Display Week: 1

Project Lead: Sreedurga

WBS	TASK	LEAD	START	END	DAYS	% DONE	WORK DAYS
1	**Report**			-			-
1.1	Find new location		Sun 1-26-20	Sat 2-01-20	7	0%	5
1.2	Mechanics of the machine		Sun 2-02-20	Sat 2-08-20	7	0%	5
1.2.1	Soil properties		Sun 2-02-20	Sun 2-02-20	1		
1.2.2	Soil mechanics (external forces)		Mon 2-03-20	Tue 2-04-20	2	0%%	2
1.2.3	Stress in structural members		Tue 2-04-20	Fri 2-07-20	4	0%	4
1.2.4	Power requirements		Fri 2-07-20	Sat 2-08-20	2	0%	1
1.3	Finalize Materials		Sun 2-02-20	Tue 2-04-20	3	0%	2
1.4	Local suppliers and manufacturers		Tue 2-04-20	Fri 2-07-20	4	0%	
1.5	Social Impact		Sun 2-09-20	Sat 2-15-20	7		
1.6	Environmental Impact		Sun 2-16-20	Sat 2-22-20	7	0%	5
2	**Tests & Simulations**			-			-
2.1	Build frame on solidworks		Sun 1-26-20	Sat 2-01-20	7	0%	5
2.2	Begin simulation		Sun 2-09-20	Sat 2-15-20	7	0%	
2.2.1	Determine stresses		Wed 2-12-20	Sat 2-15-20	4	0%	3
3	**Construction**			-			-
3.1	Disassemble the seeder		Sun 1-26-20	Sat 2-01-20	7	0%	5
3.2	Attach row & discs & make inventory for parts		Sun 2-02-20	Sat 2-08-20	7	0%	5
3.3	Order parts		Sun 2-09-20	Sat 2-15-20	7	0%	
3.4	Finish building		Sun 2-16-20	Sat 2-22-20	7	0%	
3.5.	Test seeder		Sun 2-23-20	Sat 2-29-20	7	0%	5
4	**Design Evaluation**			-			-
4.1	Risk Factor Matrix		Sun 2-23-20	Sat 2-29-20	7	0%	5
4.2	Financial Analysis		Sat 2-29-20	Fri 3-06-20	7	0%	5
							-
							-



[not followed exactly as shown]