ANIMAL-DRAWN CONSERVATION-TILLAGE PLANTER FOR SMALL FARMS IN THE DEVELOPING WORLD

A Thesis

by

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ABSTRACT

South Africa has the potential to serve as a bridge between large scale farming in developed nations and the small scale operations of subsistence farmers in developing nations. It has a mix of both large-scale modern farms and small farms, which use a range of different farming practices and products. There is a gap between the tractors used by large scale South African farmers and the equipment available to the small farm holders. This research effort aims to fill a portion of that gap. There is a particular need for implements that take advantage of newer conservation methods, such as no-till, and make that technology available for small farm holders. International shipping tends to be costly, increasing the end cost of planters manufactured in other countries, making in-country manufacturing desirable. The objectives of this work included designing, building, and testing a small animal-drawn no-till planter that could be manufactured in a rural town in South Africa and is simple and easy for men, women and older children to use. A prototype was manufactured with basic machine shop equipment and skills. The prototype was then refined and tested. Measurements included draft, seed depth, and seed spacing, with cowpeas used as a representative crop. The average draft for the prototype was 796 N (179 lbf), low enough to be pulled by two draft animals weighing 816.5 kg (1800 lbs) total. The target seed placement depth for cowpeas of 2 cm was achieved within 25% most of the time, and the target seed spacing of 10 cm was achieved within 50%. The residue managers for moving straw from the row, and the press wheels for covering the seed with soil, both performed their intended functions.

The planter was also found to be easy to lift at the tongue with one hand and easily operated from the side from which animals are typically driven. This planter could meet the planting and conservation needs of many small farm holders who have access to animal power but not to machine power.

ACKNOWLEDGEMENTS

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INTRODUCTION

Throughout much of the developing world, undernutrition is a major cause of illness and death. It is estimated that one third of child deaths in the world and as much as 10% of global diseases are attributable to undernutrition of children and mothers (Black et al., 2008). Many African countries fall into the category of developing nations, (International Statistical Institute, 2014) including South Africa. However, it is relatively wealthy, has a large capacity to increase productivity, and has influence on neighboring nations. This makes South Africa a strategic location for improving food security on the African continent. South Africa's GDP (gross domestic product) has risen steadily over the last decade and social, environmental and infrastructural improvements have continued for the past 19 years (World Bank, 2014). On the other hand, there is a wide gap between the urban rich and citizens in disadvantaged townships and rural areas (World Bank, 2014) where there are many poor farmers.

In South Africa today, there are three basic types of farmers: (1) large-scale commercial farmers who can afford large equipment and often apply new technologies on their farm; (2) small farm holders who have too much land to farm by hand but cannot afford to own a tractor – these farmers also have limited knowledge and/or equipment to apply new techniques and technology to their farms; and (3) small subsistence farmers who cultivate only as much land as they can work by hand. For the latter two groups, a great deal of time and energy is spent in the processes of preparing the soil, planting the crop and controlling weeds. Small farm holders are defined as having a mixture of cash and subsistence crops and a farm size of 2 to 10 hectares (ha). Such farms in South Africa and many other developing nations are too large to successfully farm with hand equipment, but the farmers are financially incapable of acquiring tractors or other large machines. It is estimated that one person can cultivate by hand about 0.4 hectares of land (Kumwenda, 1999). One of the quickest ways to begin addressing food shortages in Sub-Saharan Africa is to address the problems of small farm holders. One approach to improving small farm holders' economic sustainability is to develop a farming system that incorporates mechanization in a culturally relevant way while requiring less time, having the same or greater crop yields, and being affordable.

There are 900,000 km^2 of agricultural land in South Africa, about 12% of the total land (SouthAfrica.info, 2014a). Maize and sorghum are the two main cash row crops in South Africa (SouthAfrican.info, 2014b), with 12.5 million tons of maize being produced (USDA, 2013) and 20 million tons of sorghum (Taylor, 2003). Many other crops are widely grown for cash and subsistence, but it is helpful to limit the scope of this research to the study of one crop that has applicability on small farms across much of Africa. Cowpea (*Vigna unguiculata)* is a common crop for small farm holders. It is used for both animal feed and human consumption throughout Sub-Saharan Africa (CGIAR, 2014).

Agricultural research has been shown to promote GDP growth and reduce poverty in Sub-Saharan Africa (Alene and Coulibaly, 2009) by reducing rural poverty and urban poverty (Norton, 2004).

Soil erosion significantly decreases food security by reducing the crop productivity of the soil (Pimentel 2006). Research has shown that conservation tillage, no-till in particular, has many economic and environmental benefits throughout the world by preserving soil organic matter and tilth. No-till is a particular type of conservation tillage defined as disturbing the soil as little as possible and maintaining a constant soil cover of crop residue or mulch year-round (Mchunu et al., 2011). Fields under no-till tend to have higher soil organic matter in the surface horizon (Duiker and Beegle, 2006), and long term implementation can increase soil organic carbon deeper in the soil profile (Lafond et al., 2011). A major benefit of the no-till system is a reduction in soil erosion by a factor of 3 to 10 compared to conventional tillage techniques, depending on the amount of soil disturbance (DeLaune and Sij, 2012; Mchunu et al., 2011). Despite the environmental benefits, the economic benefits associated with no-till must justify the effort and cost of the switch or the farmer will not implement them.

Results from a study in Nigeria suggest that no-till provides better yields under poor growing conditions such as lack of moisture (Obalum et al., 2011) and with fewer fertilizer applications over long periods of time (Lal, 1987). Any reduction in inputs is of great importance for small farmers because they often do not have the economic means to irrigate or fertilize at recommended levels, if at all. Other studies concur that overall expenses for crop production such as fuel, time, water, and fertilizer, can be reduced with no-till, while obtaining comparable yields (Johansen et al., 2012). The labor requirement for crop establishment under no-till has been shown to be as much as 50%

less than that of conventional tillage, but the amount of labor needed for weed control is increased by about 30% (Rockstrom et al., 2009).

The use of animal traction is a convenient intermediate step between farming by hand and fully mechanized farming, and it offers real potential for the small farm holder. Using animal traction on these small farms can increase the amount of land that can be farmed as well as the likelihood of food self-sufficiency (Jolly and Gadbois, 1996). As many as 40% of small farm holders in South Africa use animal traction of some kind for plowing, and another 10 to 15% use it again for planting (Starkey et al., 1995). The average draft animal can pull 10 to 14% of its body weight for 8 hours (Goe and McDowell, 1980). The typical small farm holder in South Africa is at least familiar with animal traction and could benefit from the introduction of newer farming technologies, such as no-till, that can be integrated into power systems, such as draft animals, that they have in place.

REVIEW OF LITERATURE

Options for animal-drawn implements not designed for conservation tillage include the ard-type plow (Figure 1) and the moldboard plow (Figure 2). The ard-type is a primary tillage implement used for breaking up the soil, though it does not turn the soil over completely. It has been largely unchanged for centuries and is used throughout Africa (Gebregziabher et al., 2006). The moldboard plow is also used for primary tillage and can be animal-drawn, but it tends to have greater draft because it breaks up the soil and inverts it. When comparing the moldboard plow and the ard plow, it is clear that both present significant problems for African small farmers. Moldboard plows are heavy, difficult to repair, and expensive, often because they are imported from another country. They also leave the soil in a state that is vulnerable to erosion. The ard plow is lighter and made predominantly of material that is available locally, but it requires multiple passes over the same ground and more time. On the other hand, it leaves the soil less vulnerable to erosion than the moldboard plow. Some recent research has been done to improve the ard plow (Gebresenbet et al., 1997), but it would not change the operational limitations of the implement, such as the number of passes over a field that would be required.

Figure 1: Ard plow

Figure 2: Moldboard plow

Current options for animal-drawn devices that employ conservation-tillage techniques are limited in South Africa. The Piket Implements company produces a single-row, tine-type, no-till planter. This planter requires two oxen to pull it, indicating that its draft is fairly high. Each unit costs between 1000 and 1500 USD depending on how many units are purchased (Alibaba, 2014). Research has also been performed to develop an animal drawn punch planter for Africa. It was designed to be low-draft and perform well over most surface conditions. This planter would require a large enough investment that it has been suggested that groups of people pool their resources to invest one (Scheidtweiler, 2000).

In many places around the world, various types of no-till/low-till systems have been developed that are either animal-drawn or can be drawn with a small tractor. A three-row, animal-drawn, zero-tillage, small-grain seeder was developed in Bolivia, South America. This system was designed to be light, easy to use, and easy to maintain (Wall et al., 2003), but it is cost-prohibitive to ship to South Africa. The Fitarelli company, based in Brazil, produces several versions of a two-row animal-drawn planter (Fitarelli, 2014), which is also cost-prohibitive to ship to South Africa. The cost of shipping one 6.1 m (20 ft) cargo container to Cape Town, South Africa is about $5,800 (USD) (Movehub, 2014) depending on the point of origin in South America.

There are a number of devices used for the soil-opening function of conservation-tillage planters. Some of the common ones are tines, single disks, and double-disk furrow openers. Double-disk furrow openers have been shown to cause the least amount of soil disturbance and variation in seeding depth and require a lower level of draft than other types of furrow openers (Chaudhuri, 2001). The larger the angle between the disks, the higher the draft and the more soil that is moved laterally, leaving less soil to cover the seeds (Morrison Jr et al., 1988).

Single and double narrow press wheels, and single wide press wheels, are all common. There is no statistical difference in most measured parameters observed regarding the effectiveness of press wheels (Bahri and Bansal, 1992).

Crop residue on the soil surface can have a negative impact on seed placement depth and uniform emergence of the crop. Several types of residue managers are used; row cleaners and coulter disks are two of the more common types. Residue managers can remove residue directly over the row, preventing these negative effects (Rauofat and Matboei, 2007). They are easy to manufacture without expensive machining tools, making them ideal for simple designs.

There is not an economically affordable, multi-row, conservation-tillage planting implement in South Africa. In order for South African small farm holders to implement conservation tillage and gain from the benefits of such techniques, access to affordable conservation-tillage agricultural equipment is needed. Producing that equipment in South Africa with material and manufacturing technologies available in South Africa, particularly in moderate-size cities in rural areas, would eliminate international shipping costs, making the equipment more accessible to the small farm holder.

OBJECTIVES

The overall goal of this project is to develop an animal-drawn no-till planter that is suitable for small farm holders and can be manufactured in rural South Africa with techniques that can be performed there with materials and parts that are locally available. Specific objectives include (1) developing a planter design that adheres to detailed design criteria, (2) constructing and refining a prototype, and (3) field testing to ensure functionality and intended performance. The design criteria are (a) draft that is low enough that the planter can be powered by draft animals or a small tractive machine, (b) ability to plant cowpeas to the appropriate depth and at an appropriate seeding rate, (c) employment of conservation tillage, and (d) variable two-row configuration so that the planter can plant quickly if adequate tractive power is available.

MATERIALS & METHODS

Design Phase

On a January 2013 trip to Ukulima Farm in the Limpopo Province, South Africa, the author made a number of observations to develop the planter design criteria for an improved planter that would be appropriate for African small farmers. Soil characterizations were not available for that location, but soils were sandy within the expected zone of cultivation. Soil pits dug near fields showed very sandy soils to a depth of approximately 2 m overlying plinthite (iron accumulation). During this trip the Fitarelli planter was assessed, and notes were taken concerning its construction and the feasibility of constructing a similar device in South Africa. These observations were then taken into consideration in the planning phase of the design.

To begin the design phase of the project, a list of constraints was created based on the design criteria laid out in the previous section. One constraint is the availability of tools for the construction of the planter. The planter was designed to minimize the number of expensive or highly technical tools required in the construction. The planter was designed to be constructed with a welder to attach many of the metal pieces to one another, a drill for cutting holes, a metal grinder, a metal cutter that could be either a chop saw or a torch, and a few hand tools such as wrenches and hammers for attaching bolts and screws.

A 3-D CAD drawing (Figure 3) was created in Solidworks software based on the constraints and design criteria. The prototype can be segregated into seven sub-systems based on functionality and construction: the frame, the seeder unit, the residue managers, the press wheels, the weight boxes, the furrow openers, and the drive system. Each system is described below, with particular attention given to the requirements needed to construct and assemble it.

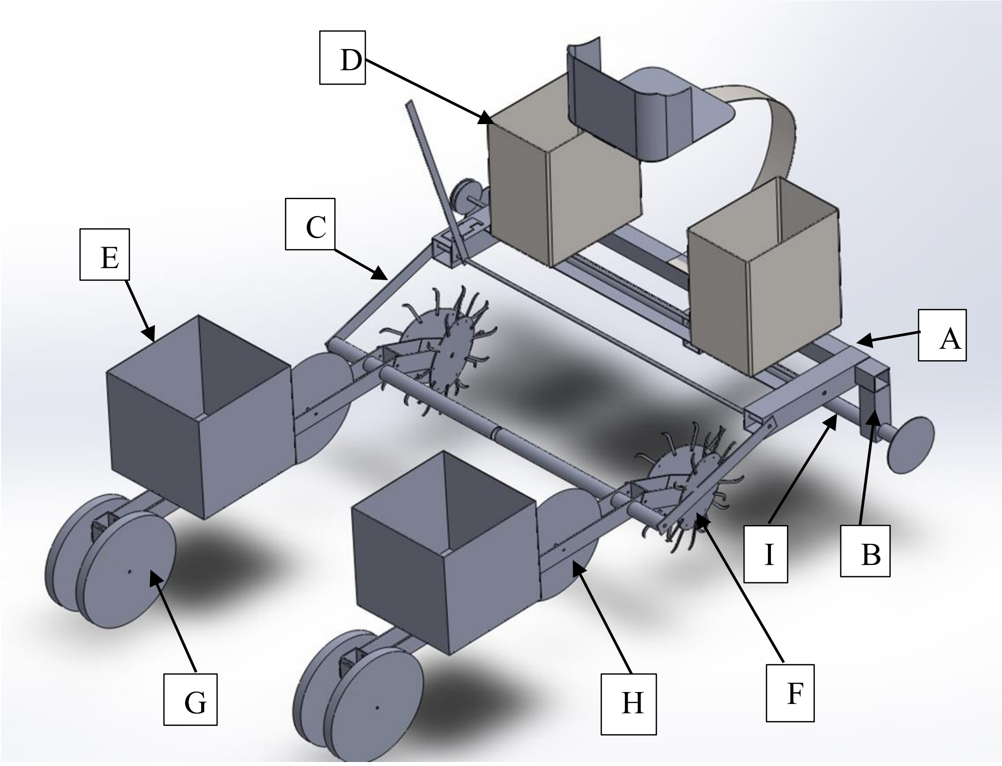

Figure 3 – 3-D Solidworks model. A) Horizontal frame B) Leg Frame C) Short Arm D) Seed Hopper E) Weight Box F) Residue manager G) Press Wheel H) Furrow opener I) Axle

Frame

The frame is designed to be constructed of steel square tubing with outside dimensions of 6.35 cm (2.5 in.) and thickness of 6.35 mm (0.25 in.) for the leg pieces, and thickness of 3.18 mm (0.125 in) for the horizontal pieces (Figure 4). This frame will support the seed hoppers, the seeding drive system, and the axle. In designing the main frame it was determined that the center of gravity should be slightly behind the axle and slightly above it. Building the frame in this way would balance the weight largely behind the axle with the weight of the tongue that is in front of the axle. Doing so would remove much of the downward force that is normally applied to the neck of the draft animals, which can cause them to carry more load than necessary and reduces the length of the working day. Having the center of gravity at the rearward location also allows one person to easily maneuver the planter when attaching it to the draft animals. In order to construct this piece, a welder must be used to connect the pieces together. Also needed is a drill to cut the holes for the axle, drive system, seed hoppers and draw bar. Some hand tools are also needed for attaching the bolts for the bearings.

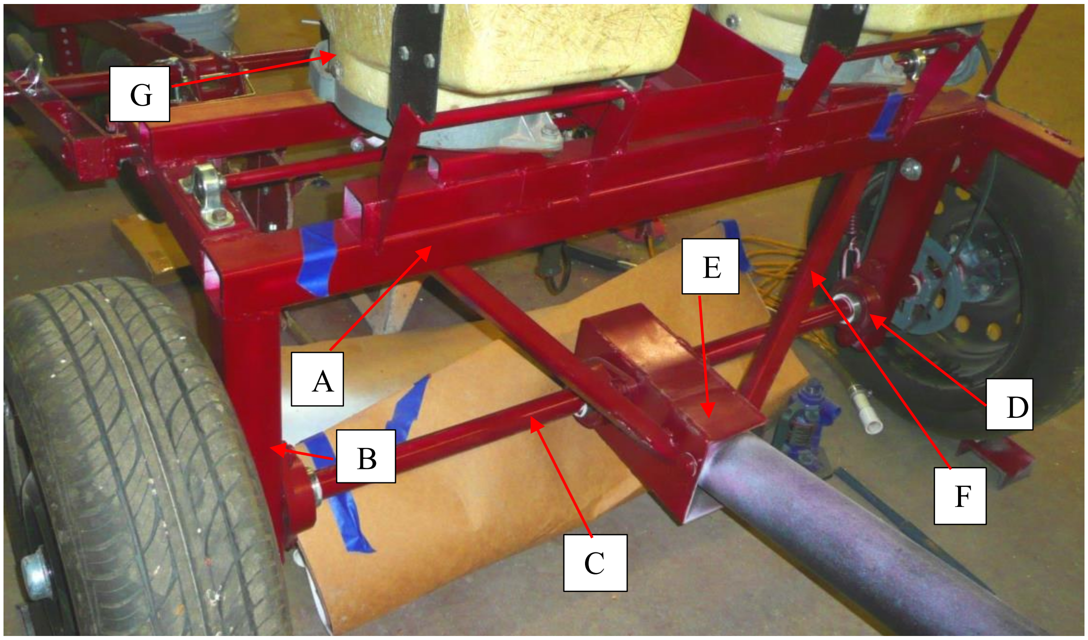

Figure 4 – Original Prototype Constructed frame. A) Horizontal frame piece B) Leg frame piece C) Axle D) Flange bearings E) Tongue box F) Tongue Support piece G) Seed hopper.

The seed hoppers sit on top of the frame, attached at the front with a bracket and attached at the rear with a clip. The seed hoppers used in this research were a pair of used Case-IH 900 model hoppers, thus having gear drive and gravity feed. These seed hoppers are not ideal for this application but they do enable the rest of the prototype subsystems to be tested.

The axle and draw bar are attached with flange bearings, which are attached to the frame with two bolts and to the round bar that passes through them with a set-screw. The bearings used on this prototype are simple non-sealed flange bearings because they were readily available at the time. Later during the refinement phase sealed flange bearings were found at an online retailer that would work for this application. Using sealed bearings would add a little to the cost of the implement, but the reduction in maintenance would probably be worth the small increase in up-front cost for a production model. A tongue box, located at the center of the axle, is used to attach the tongue to the planter. It has inside dimensions of 10.16 cm (4 in.) wide by 15.24 cm (6 in.) tall and is made of 4.76 mm (3/16 in.) plate steel. It also has two flange bearings attached to each side. There are two supports that run from each side of the box up to the bottom of the horizontal frame piece. These supports are 2.54 cm (1 in.) steel square tubing that is 9.53 mm (3/8 in.) thick. The supports are designed to distribute the pulling force across the frame instead of concentrating it on the axle.

Seeder Units

The seeder units trail behind the main frame and are attached by the short arms. They consist of the residue managers, furrow openers, weight boxes and press wheels (Figure 5). The seeder units are designed to be constructed of 5.08 cm (2 in.) wide flat bar stock that is 6.35 mm (0.25 in.) thick. They are attached at their front end by passing a round pipe through them and placing a pin on either side. These pins can be removed, and the seeder unit can then slide horizontally up and down the bar to change the planting row width. This bar is also lifted and lowered to engage or disengage the furrow opening operation. A MIG (metal inert gas) welder was used to build the frame for the seeder unit and a drill press to drill the holes for both the pipe at the front and the press wheel pins at the rear.

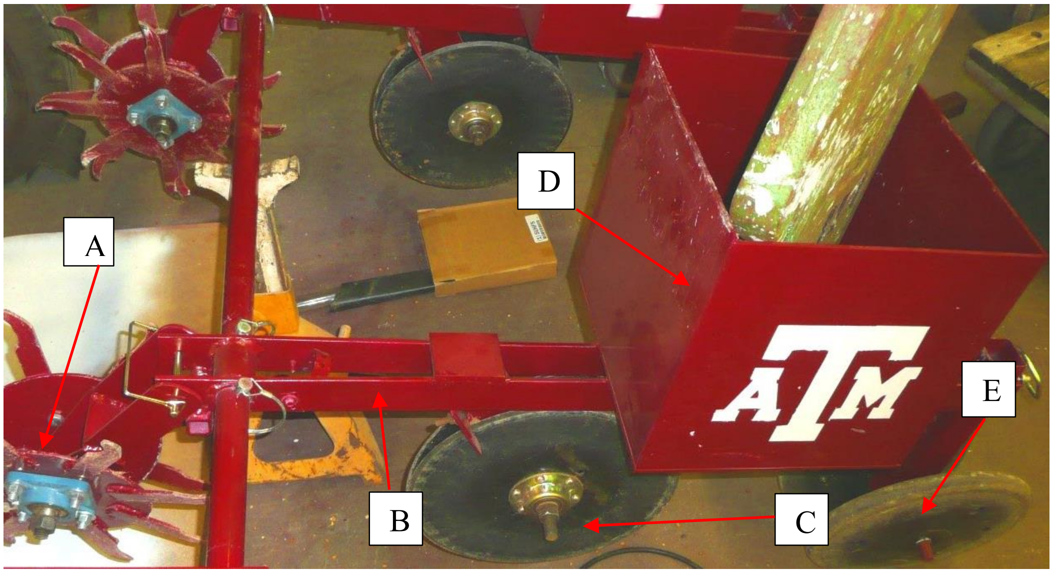

Figure 5- Constructed Seeder Unit. A) Residue manager B) Seeder unit frame C) Furrow opener D) Weight box E) Press wheel

Residue Managers

The residue managers are designed to move the residue to each side of the furrow, creating a clean soil surface for the disc openers and keeping the residue from interfering with the seeding process. They also serve the function of breaking a crust that can appear on the surface of some soils. The residue managers are set at the front of the seeder units and are designed to be constructed from 4.76 mm (3/16 in.) thick steel plate. They are circular, 20.32 cm (8 in.) in diameter, with eight hooked tines that are 20.32 cm (8 in.) long, extending out evenly and spaced along the perimeter (Figure 6). They are attached to the front end of the seeder units and have a four-bolt flange bearing that allows them to spin at the speed the planter is traveling. The tines of the residue managers are set at an angle such that they interlace at the point where they meet the ground. The disks of the residue managers are set on an A frame made of 4.76 mm (3/16 in.) thick steel plate members. A MIG welder was used to build the frame and to attach the tines to the disks. A drill press was used to drill the holes in the center of the disks as well as the holes needed to attach the flange bearing.

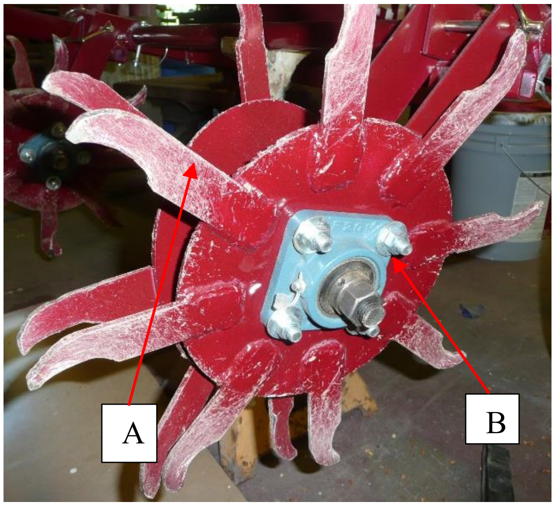

Figure 6- Constructed Residue Manager. A) Tine B) Flange bearing

Press Wheels

The press wheels are set at the back end of the seeder units. They are designed to cover the seeds and establish good seed-to-soil contact. The original design includes two press wheels on each unit attached to 5.08 cm (2 in.) steel square tubing of 3.18 mm (1/8 in.) thickness. They are placed at a downward angle of 16 degrees from the centerline, with a 1.59 cm (5/8 in.) piece of round rod. A hole is drilled in this rod in two places, and a cotter pin is placed on the front and back side of the wheel to hold it in place (Figure 7). When the furrow-opening operation is disengaged, the press wheels support the weight of the seeder unit and trail behind the main frame.

Figure 7- Original Press Wheel Construction.

Weight Boxes

Weight boxes were designed to increase the penetration of the furrow opener so that seeding depth can be varied by changing the weight in the boxes. They are constructed of 4.76 mm (3/16 in.) steel plate, designed with an inside dimension of 30.5 cm by 30.5 cm by 30.5 cm (12 in. x 12 in. x 12 in.), and they are attached to each seeder unit 7 in. behind the furrow openers (Figure 8). They are constructed so that many different types of weights can be used such as conventional tractor weights or natural substitutes like soil and rocks.

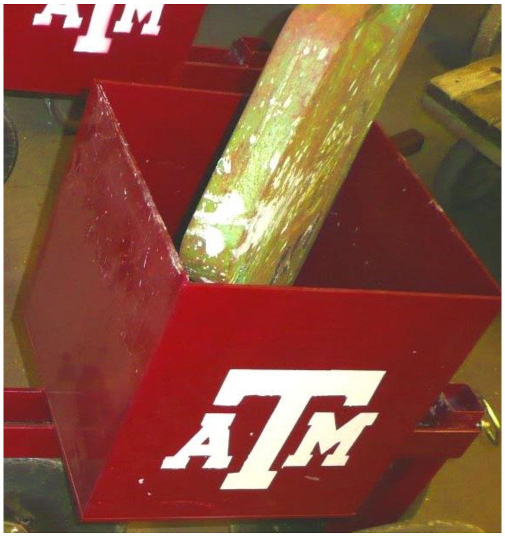

Figure 8-Constructed Weight Box.

Furrow Openers

The seeder units were designed with a double-disk furrow-opener system. The double disk openers are attached to the seeder unit approximately half way down its length. A bar is welded across the top that has a shank located in the center, extending down 27.9 cm (11 in.). The shank is 5.08 cm (2 in.) wide by 1.27 cm (0.5 in.) thick. A 1.59 cm (5/8 in.) threaded rod is mounted on the shank at an angle of 16 degrees from the center line and forward by the same amount so that the two disks are touching at the point where they contact the ground when they are mounted on the rods (Figure 9). Each double disk opener also has a scraper mounted on it. This scraper is a flat piece of 3.18 mm (1/8 in.) thick steel plate with a notch cut in it that matches the angle of the disk. It is then bolted to another piece of 3.18 mm (1/8 in.) thick plate that is welded to the frame of the furrow opener. It is designed to scrape off soil that would otherwise stick to the double disk and reduce the effectiveness of the furrow openers.

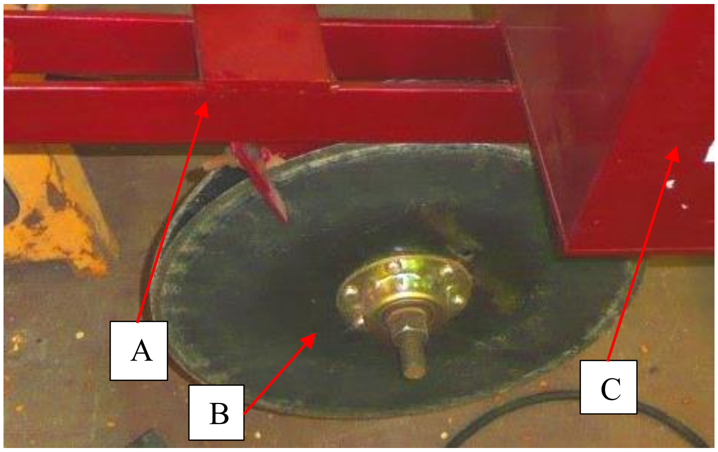

Figure 9-Double Disk Furrow Opener. A) Seeder unit frame B) Furrow opener C) Weight box

Drive System

The drive system was designed based on a v-belt drive. The drive pulley (Figure 10) is the largest pulley, with a diameter of 17.78 cm (7 in.), and is located on the axle shaft just inside the left wheel. The driven pulley is located on the drive shaft for the seed hoppers and is designed such that it can be changed to vary the seeding rate to fit the planting circumstances. A tensioning pulley allows the seeding system to be engaged or disengaged when desired by either putting full tension on the belt or allowing enough slack in the belt that it slips along the drive pulley without turning. One of the benefits of this drive system is that it is low-maintenance. All parts function properly until they need to be replaced from wear, the most frequent being the v-belt. Under ideal conditions the v-belt would need to be replaced after 4 to 6 years (Dura-Belt 2014). V-belts are a readily available part at many auto parts stores in South African towns with a population of 35,000 or more.

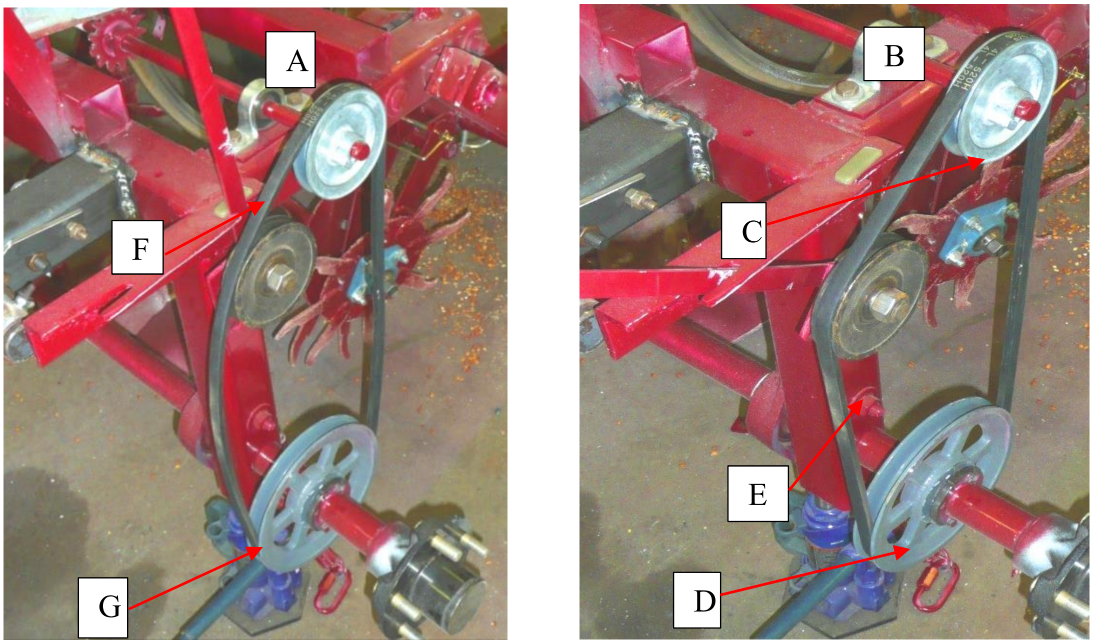

Figure 10- V-belt Drive System. A) Disengaged configuration B) Engaged configuration C)Driven pulley D) Drive pulley E)Tension pulley F) Drive system lever G) V-belt

Construction

The prototype was constructed in the Biological and Agricultural Engineering shop on the Texas A&M University campus. During construction of the prototype, processes were limited to those that can be performed in small shops in South Africa, keeping in mind the types of tools, materials, and expertise available. A metal band saw and a shear were used to cut the metal. Cutting could also be performed with a metal chop saw or an oxygen-acetylene torch. A torch was used to cut out some small pieces such as the fingers for the residue managers. A MIG welder was used to attach metal pieces together, but an arc welder could serve the same purpose. A drill press was used to drill most of the holes, and it is recommended that all holes be drilled before assembling the planter. It is also possible to drill the holes with an electric-powered hand drill, which was used when some additional holes had to be drilled after the frame had already been put together. Both a hand-held metal grinder and a bench grinder were used, but it would be possible to use only a hand held grinder. A variety of small hand tools such as hammers, wrenches, and screwdrivers were also used. The minimum required were a hammer, two adjustable open-ended wrenches (of the type commonly called a crescent wrench) and two screwdrivers.

Design Refinements During Construction

During construction, some lengths of parts were changed to improve the functionality of the prototype. The most important change was to the frame legs, which were lengthened to ease the travel of the seed through the seed tubes. With the original leg height, seeds tended to get stuck in the tubes due to a shallow valley in the tubing between the seed hopper and the double disk. Increasing the leg height created a steeper angle for the seed tubes, achieving a more consistent seeding rate.

As is common in machine design, the prototype was designed with competing constraints: it was not to fail structurally, yet it was to require the smallest feasible amount of material. However, when the material was ordered it was determined that in certain cases the specified dimensions would require custom manufacturing, thus costing more than if a larger-size or thicker material were used. Furthermore, in many cases a material could only be purchased in specific lengths, meaning that more money would be spent purchasing pieces of thinner material for certain members while thicker material was being used for most others. Since one of the objectives was to produce a product within economic reach of small farm holders, it was decided to make most members of similar size out of the same material to make the design more cost-effective. Therefore, 6.35 cm (2.5 in.) square tubing of 6.35 mm (0.25 in.) thickness was used for all the frame pieces, rather than the 3.17 mm (0.125 in.) thickness of some pieces in the original design.

A similar decision was made regarding the handle used to engage/disengage the seeder units. Rather than buy another 6.4 m (21 ft.) piece of the specified size, some of the leftover piece of 2.54 cm (1 in.) square tubing that had been used for bracing on the tongue was used to construct the handle. This size was larger than required, but using it reduced the price of the end product by reducing the overall amount of material purchased.

Design Refinements During Testing

During construction, preliminary testing was conducted to determine whether the different systems performed as expected. During these tests it was found that the drive system, the engage/disengage system, and the press wheels needed refinement.

The drive system was designed with a drive pulley, driven pulley and idler pulley all of the same size, 7.62 cm (3 in.) in diameter. However, it was discovered during preliminary tests that the seeding rate was too low for cowpeas. To increase the seeding rate, a larger drive pulley was placed on the axle. The driven pulley on the seed hopper drive shaft can still be changed to vary the seeding rate within the desired range. There was an additional problem related to the tension pulley. The tension pulley arrangement was designed to keep the belt tight with a torsion spring, but the size of torsion spring used was not large enough to keep the belt from slipping. Because of this a notched place holder was built so that the seeding system could be engaged by moving the engage lever into the correct notch to hold the tension pulley in place and keep the belt from slipping. This place holder is built from 2.54 cm (1 in.) by 2.54 cm (1 in.) angle iron that is 6.35 mm (0.25 in.) thick (Figure 11). Smaller angle iron could possibly be used.

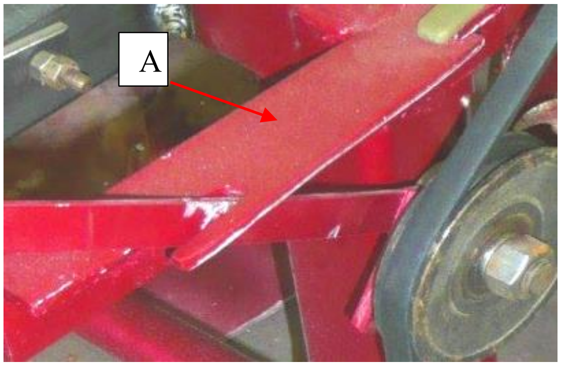

Figure 11- V-belt Drive System Handle Bracket. A) place holder

The engage/disengage system as it was originally designed did not work well. The system did not have a sufficient mechanical advantage to reduce the lifting load enough to be easily operated. It was redesigned such that the seeder unit could be picked up with a cable that passes over several pulleys and attaches to a wheel 10 in. in diameter. The lever attached to the wheel is 76.2 cm (30 in.) long, giving a mechanical advantage of 20 (Figure 12). The lever can be locked into place with a catch system (Figure 13). Leftover 3.5 cm (1.375 in.) tubing was used to construct the lever.

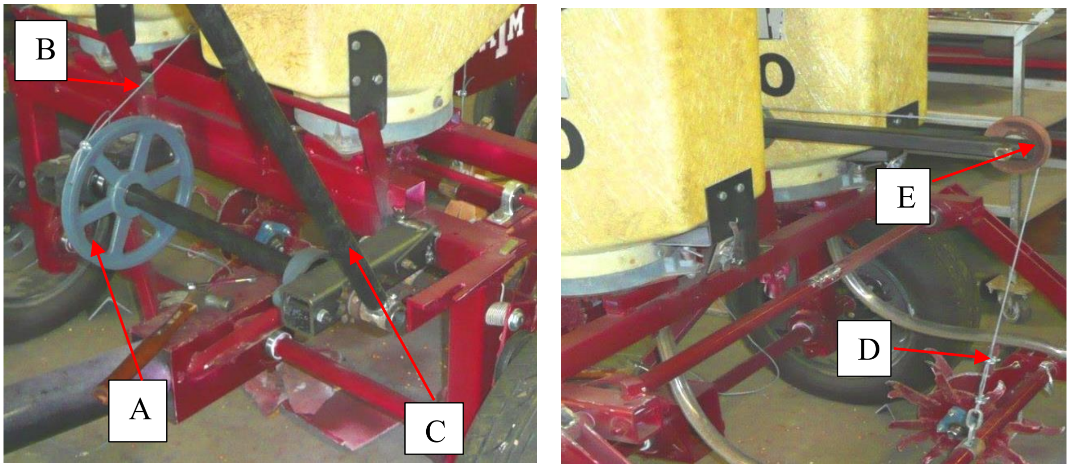

Figure 12- Refined Engage/Disengage system. A) Wheel B) Cable C) Lever D) Cable E) Pulley

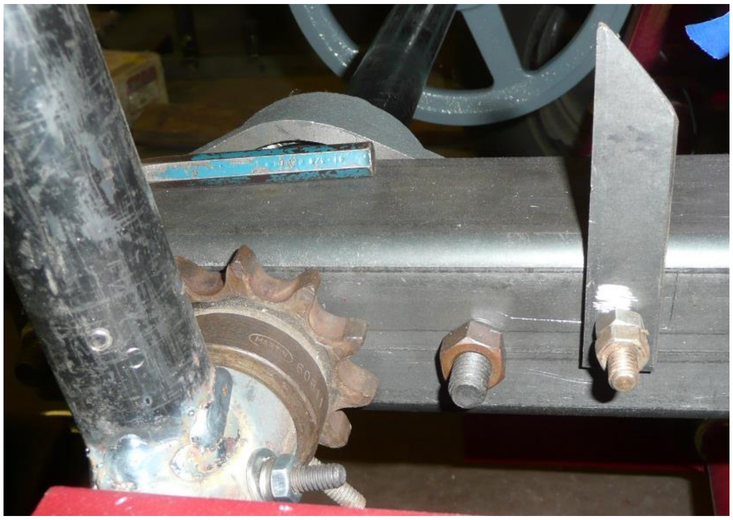

Figure 13- Refined Engage/Disengage locking system

The press wheels in their original configuration experienced a perpendicular force when the planter was turned. This force caused excessive wear and premature failure of some of the press wheels. To solve this problem a single 25.4 cm (10 in.) diameter wheel on a caster was attached to the original mounting system (Figure 14) as a replacement. This change allowed the press wheels to turn with the planter, relieving the perpendicular force applied to them.

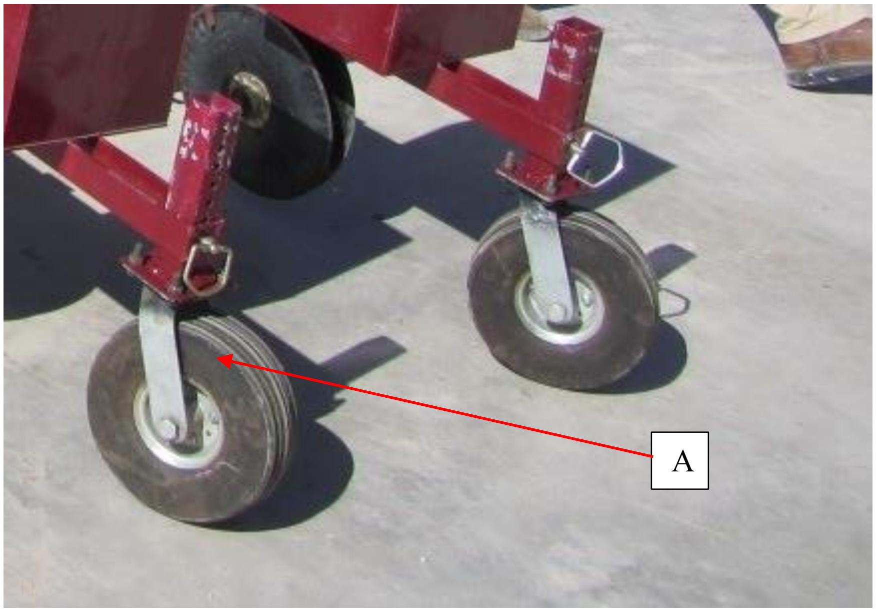

Figure 14-Final Press Wheel Configuration. A) New press wheel assembly

Expected Maintenance

The planter is designed to be low-maintenance. In order to keep the frame in top operating condition the bearings should be greased on regular intervals, and a coat of paint needs to be kept in place to prevent rust. The planter has six bearings that need to be greased. Even if not properly maintained they are easy to replace when worn out. As mentioned previously, the planter’s v-belt needs to be replaced after 4 to 6 years under ideal conditions (Dura-Belt, 2014). The seed tubes would also need to be replaced. Under ideal conditions the useful life for this tubing is 3 years (Zippertubing, 2014). There are two car tires and four press wheels that also would eventually need to be replaced, and depending on the soil, the furrow openers could also need to be replaced after a number of years. All of these parts can be replaced with simple hand tools to remove bolts and nuts, and all parts are available in South Africa. The parts that are most likely to need replacing are common in towns that are located on a paved road and have a population of 35,000 or greater. This analysis is based on the size of towns close to Ukulima Farm, where the author has some knowledge of the types of material available. In order to ensure that parts would be available and close to the same prices as those found in the U.S., a search for those parts was conducted on www.google.co.za (2013). The staff at Ukulima Farm in the Limpopo Province of South Africa were also interviewed concerning the availability of certain parts in the towns close to the farm.

DATA COLLECTION AND ANALYSIS

Site Description

The primary set of field tests took place at the Texas A&M AgriLife Research Farm in Burleson County, TX, (latitude 30.54547°, longitude -96.43111°). The soil at the test location is a Ships clay with a 1 to 3 percent slope (NRCS 2014). The field used for testing was tilled fallow. It had been tilled roughly 6 months before.

A secondary test location was Wilcox, Arizona. The intention for this location was to connect the prototype to two oxen and observe how well the planter performed, including taking draft measurements and visual observations of overall planter operation. Of particular interest was the pivoting at the end of each row. While at Wilcox, hooking up the oxen and making passes with the planter in the disengaged configuration allowed us to observe how easily the planter maneuvered under animal power, and to gauge the ease with which one person could connect the planter to the oxen. In both cases the prototype performed well.

Draft Data Collection

In the tests at the Texas A&M AgriLife Research Farm in Burleson County, Texas, a John Deere 2555 tractor was used as the power source. A three-point hitch frame with an eye bolt was constructed, and the tongue of the prototype was attached to the eye bolt with a series of D-links, swivels, and a clevis pin (Figure 15).

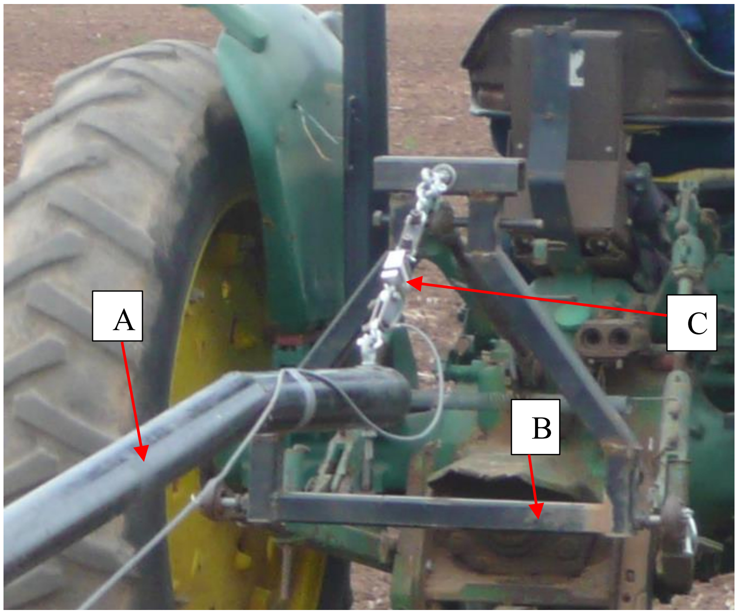

Figure 15- Prototype Hitching system. A) Tongue B) 3-point hitch C) Load cell

To measure the draft, an Omega LC-101-1.5 K load cell was used and connected to an Omega SQ-2010 data logger. The data logger was placed in a box on the planter between the two seed hoppers. The load cell was aligned with the end of the tongue between the planter and the tractor (Figure 15). This arrangement enabled measurement of the total force required to pull the planter, including vertical load. The procedure used to begin each run required the tongue of the planter to touch the three-point hitch attachment. The furrow openers were then engaged and the logging process initiated on the data logger. Next the planter was pulled forward at approximately 3.22 km/h (2 mi/h) as steadily as possible to minimize impact loading. At the end of a 50-m row the tractor was stopped and backed up until the tongue was again touching the three-point hitch attachment. The data logger was then stopped and the furrow openers disengaged. The tractor and planter were then turned around and prepared for the next run.

For one run the load of the planter was also measured when not planting by not stopping the data logger at the end of the row after disengaging the furrow opener. It was then stopped when the turn had been completed. The DAQ recorded the draft force as a voltage at a rate of 1 sample per second.

Draft Data Analysis

A calibration curve was constructed with 12 known weights from 31.75 to 281.7 kg (70 to 621 lb). The load cell was set up in a static load test with a known-weight bucket and chain. The 12 weights were placed in the bucket one at a time, and load cell output was recorded after each added weight. A graph was then produced to show points relating the known weights and the recorded voltage output from the load cell. A curve was fit to those points. This calibration curve was then used to convert the draft voltage to a draft force. A graph was then created of the force versus the time at which the force was recorded. This graph was analyzed to find the maximum, minimum, and average forces for the given run.

The following steps were used to calculate average draft. First, the graph of each run was evaluated to determine the points where the run started and stopped, and a vertical line was placed at both of those points (Figure 17). The start of the run was taken as the last data point at the zero readout value; the data from the load cell were in roughly a flat line prior to a spike caused by pulling the planter at the beginning of the run. The fact that the driver stopped pulling and then backed up at the end of each run produced somewhat of a Z shape at the tail end of the graph (Figure 16). The start of this z shape was taken as the end of the run (Figure 17). The length of the run was taken as the time difference between the start and end of the run. The net run length, used for calculating the average draft force, was the total run length minus 5% of that length at each end of the run. The points bounding net run length were labeled new start and new stop (Figure 17). The average draft values calculated for each run were then averaged together to determine an overall draft average across all tests. This value was then used to judge whether the planter could in fact be pulled readily by draft animals available in South Africa.

It is typical to report draft in the horizontal direction, although it is sometimes reported in the vertical direction also (Thomson and Shinners, 1989). Because of the method used to connect the load cell between the tongue and the three-point hitch, the measured force had both a vertical component and a horizontal component. In his review of the literature Thomson (1989) reported on a number of studies that all reported only the horizontal component of this force. Herein the horizontal component, vertical component, and combined force are all reported, but combined force is discussed most. This force, referred to as average draft, is the amount of force that the animal(s) will feel while pulling the implement through the field. Using this value gives a conservative reference to compare with the amount of draft that the animal can pull for a full work day.

At the beginning of a test run the load cell was positioned vertically, producing the vertical component of the draft. The zero line at the beginning of each run was thus used to find the average vertical component of the draft for that run by simply averaging the data points in front of the start line. The average horizontal component was found as follows: (1) both the combined force and horizontal component were squared, (2) the squared horizontal component was subtracted from the squared combined force, and (3) the square root of the result was taken to be horizontal draft.

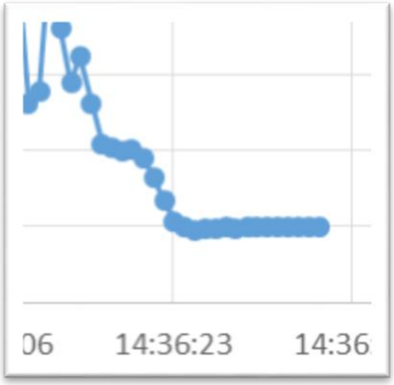

Figure 16: z shaped tail.

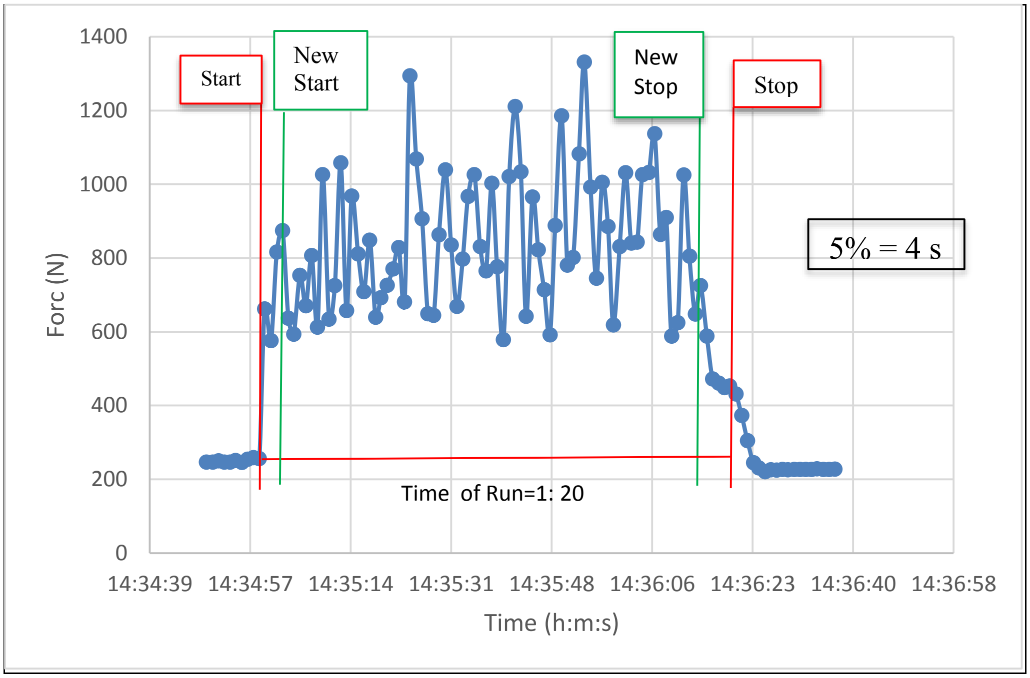

Figure 17- New Start and Stop points for Analyzing Draft Data.

Seed Placement Data Collection

To measure seed placement, a distance of 10 m was measured from the beginning of each row, and that point was marked. From that point, 1.0 m of the row was then marked off and the seeds in that 1-m section uncovered. Seed depth was measured to the top of the seed with a ruler. This procedure was performed once for each of the six rows planted.

Seed Placement Data Analysis

To analyze the seeding depth in a given 1-m section, the maximum, minimum, and average seed depth were determined along with the number of seeds found in that section. These averages were used to determine how consistently the planter places seeds, as well as indicating whether the appropriate depth can be reached. The target depth is 2 cm (Johnny’s Selected Seeds, 2014). This is at the deep end of the range of depths suggested for cowpeas, but still within the prescribed range.

Seed Density Data Collection

To measure seed planting density, the same section of planted row as in the seed-placement procedure was used. When the first seed from the beginning of the 1-m section was found, its position was marked as distance zero. The distance to the next seed was then measured and recorded. Each seed was measured in this fashion so that the distance from one seed to the next was recorded.

Seed Density Data Analysis

The average distance between seeds on each row was calculated. The target was 10 seeds per meter for the given row spacing of 76.2 cm (Johnny’s Selected Seeds, 2014), which would give an average seed spacing of 10 cm between seeds.

Seed Coverage Data Collection and Analysis

To measure the seed coverage, the 1-m section of row used in measuring seed depth was inspected. Each seed was assigned to one of three categories: good coverage, average coverage, or poor coverage. Good coverage was defined as the seed’s having soil well packed around it as it was uncovered. Average coverage was defined as having soil all around it as it was uncovered. Poor coverage was defined as having some part of the seed visible without having to uncover it or simply having large clods on top of it.

Residue Manager Effectiveness Data Collection and Analysis

To measure the effectiveness of the residue managers, straw was placed along the row, with mixed orientation, in front of the planter. The prototype was pulled through the straw for a distance of 5.0 m. A comparison was then made between the rows with residue and the ones without residue. The residue managers were then rated as sufficient or insufficient. Sufficient was defined as removing a visible amount of residue from the furrow, which was deemed to be roughly 20% or more. Insufficient was defined as not doing so, and therefore suggesting that modification to the residue managers was necessary.

RESULTS

With respect to objective 1, the original planter design adhered to the detailed criteria, but design modifications were made after the constructed prototype revealed certain practical deficiencies. The planter's row spacing can be varied between 101.6 cm (40 in.) and 35.56 cm (14 in.). The planter uses a double-disk conservation-tillage technique with residue managers in front of the double-disk, and a single wide tread press wheel behind the double-disk. The planter uses a v-belt drive system for seed dispensing, and can be operated by men, women and older children with relative ease.

With respect to objective 2, a prototype planter was constructed and refined after initial field testing. The tools used to manufacture the implement are simple, requiring only basic training and a constant power supply, both of which are available in South Africa. The material is readily available in South Africa for prices comparable to those found in the United States. A number of refinements were made based on initial testing. The resulting prototype after those changes met objective 1.

With respect to objective 3, field testing validated the design as well as the refined prototype planter. Objective 3 was broken into several categories: draft, seed depth, seed spacing, and how well the mechanical components preformed.

Draft

The force the data logger recorded before the unit starts moving averaged roughly 246 N (~55 lb). This is the vertical component of the force, which is the weight of the planter that is resting on the oxen yoke at all times. This force is the zero line for the graphs of force versus time.

Figures 18 through 23 show the draft force on the y-axis and time on the x-axis. The start and end of the runs can clearly be seen where the draft rests at the zero line of 246 N (~55 lb). Figures 18, 19, 20 and 23 show a typical range of values for draft of the planter on tilled fallow soil. Figure 21 shows a flat spot in the middle of the graph where the recorded draft is roughly in line with the zero line. This anomaly correlates to a stop mid-run to adjust part of the prototype that was not set properly for one of the rows. The fact that it is not exactly even with the zero line is explained by the fact that the planter does not roll forward when the tractor comes to a stop but rather comes to an instant stop, keeping a small amount of tension on the load cell. Figure 22 shows a complete run followed by a period of zero readout and then another run. The second non-zero portion in Figure 22 corresponds to the draft required while turning the prototype around. During this maneuver the furrow openers were disengaged, and as expected the recorded draft was considerably lower than when they are engaged.

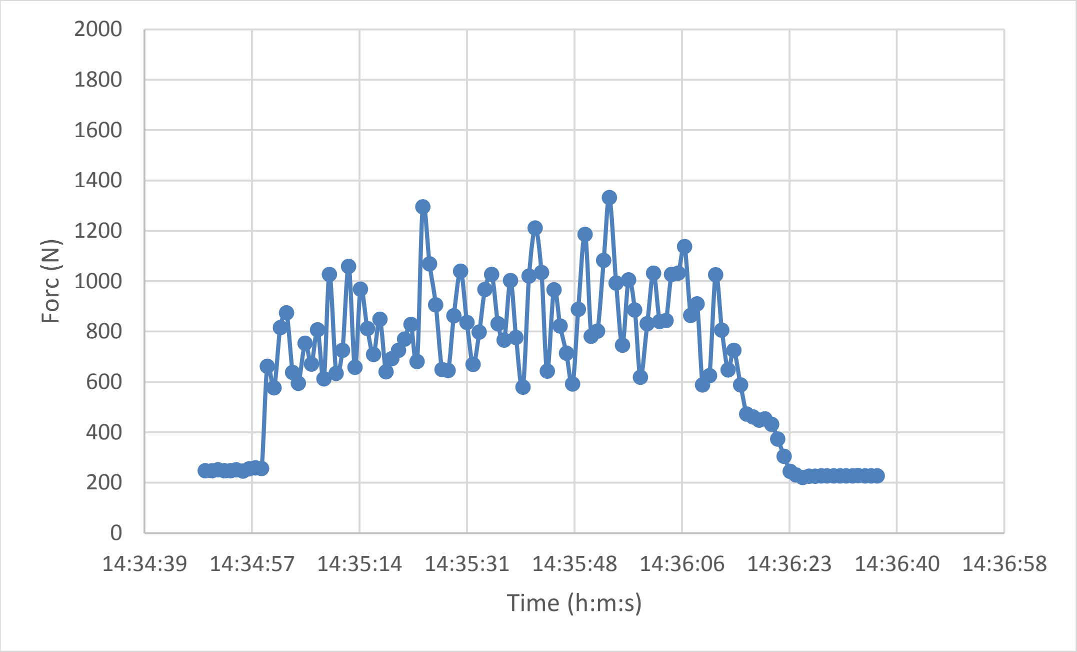

Figure 18- Graph of draft v. time for run one.

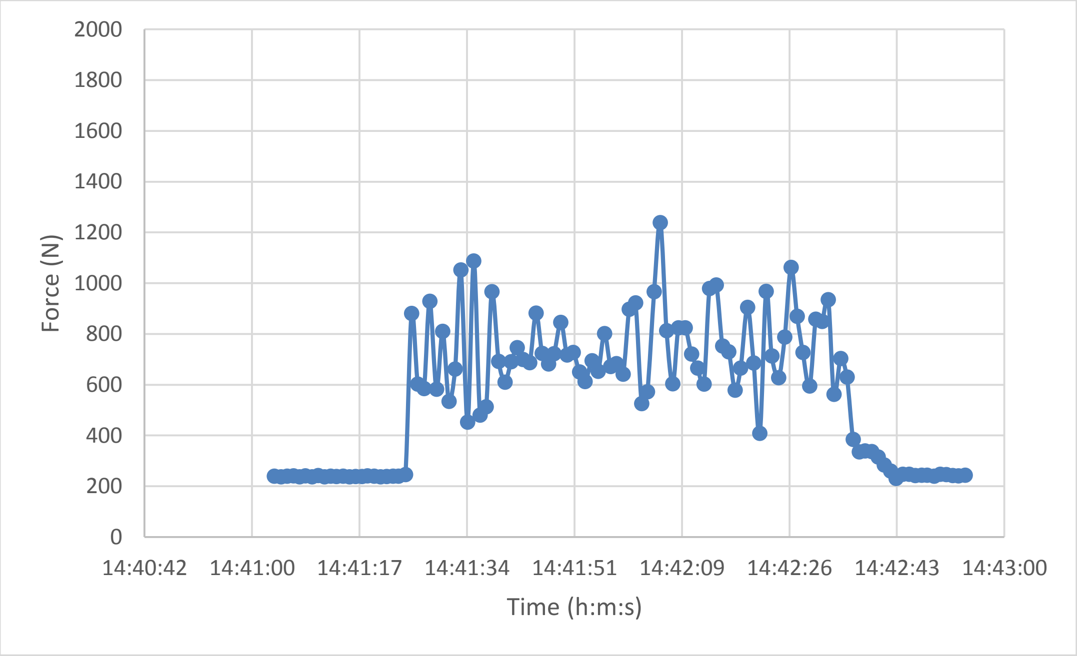

Figure 19- Graph of draft v. time, for run two.

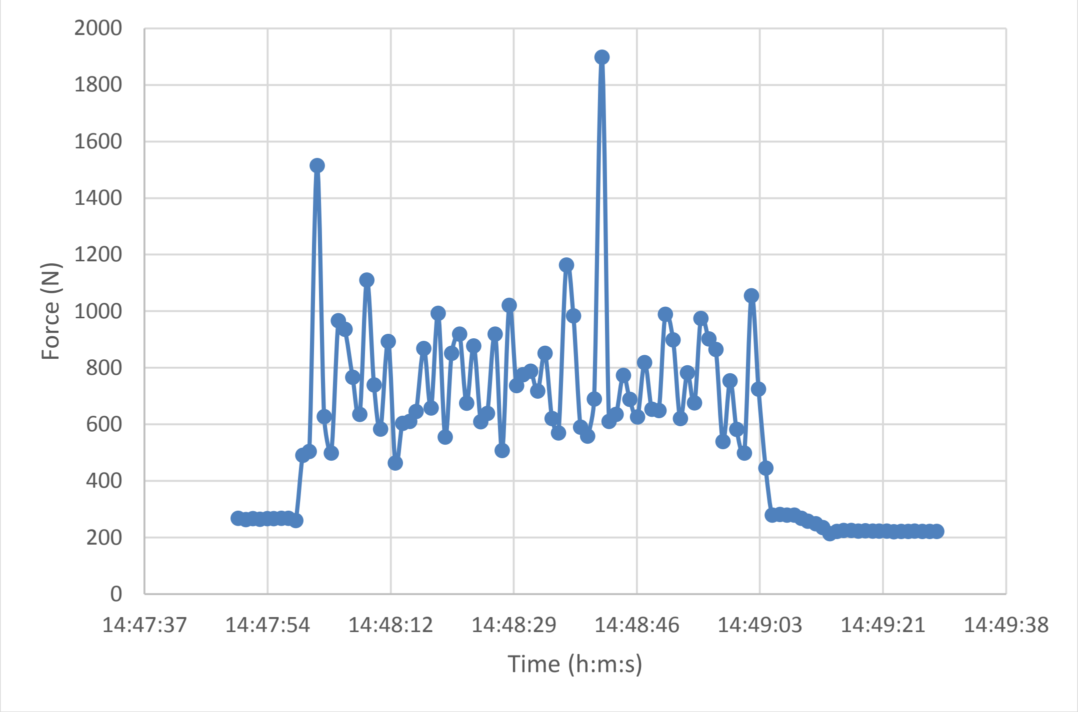

Figure 20- Graph of draft v. time, for run three.

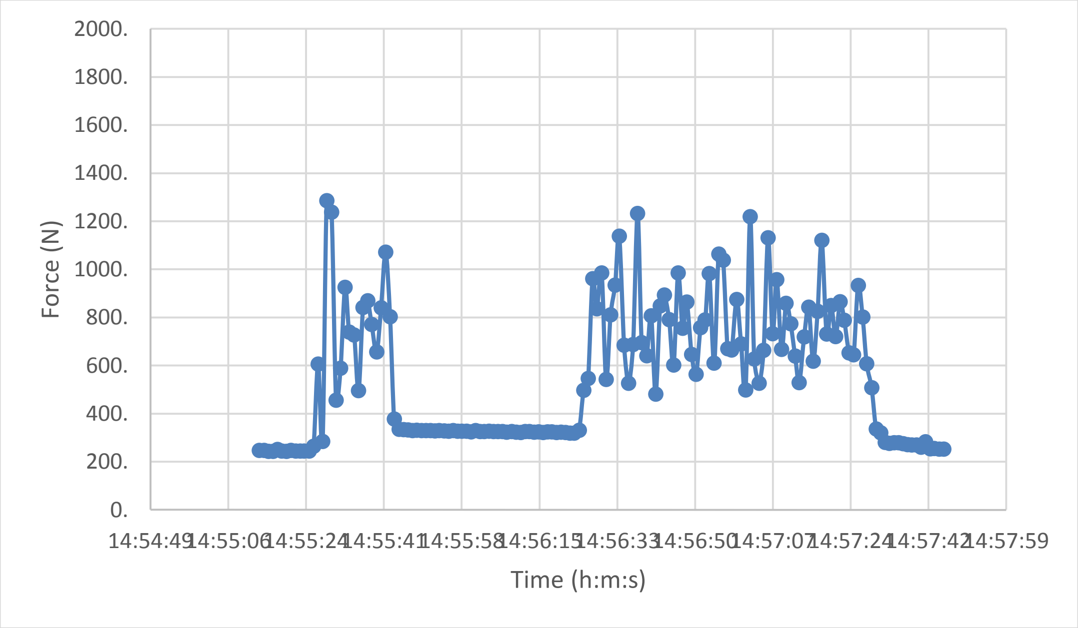

Figure 21- Graph of draft v. time, for run four.

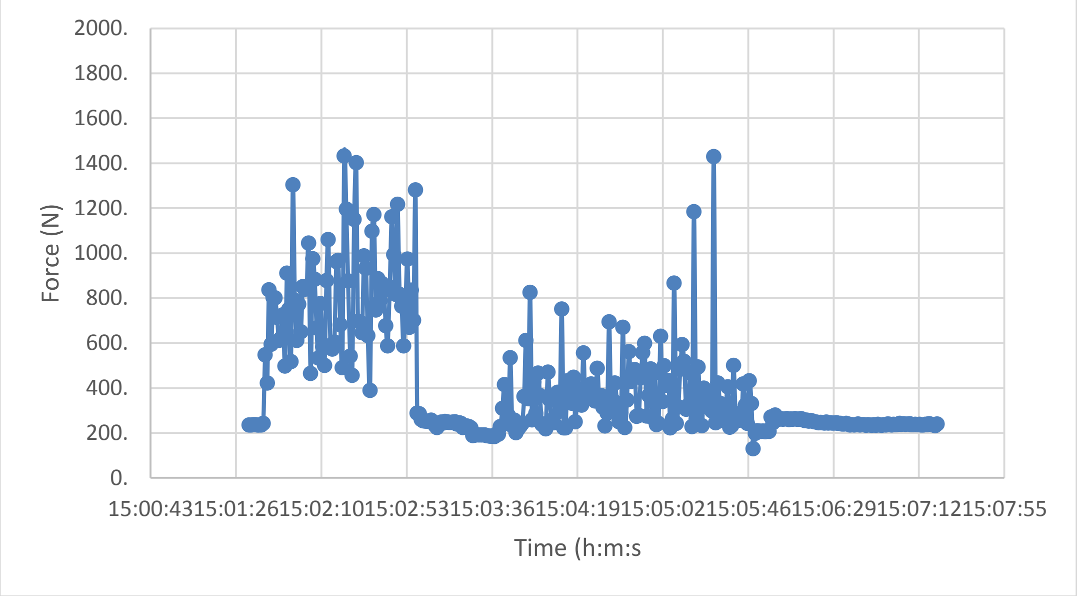

Figure 22- Graph of draft v. time, for run five.

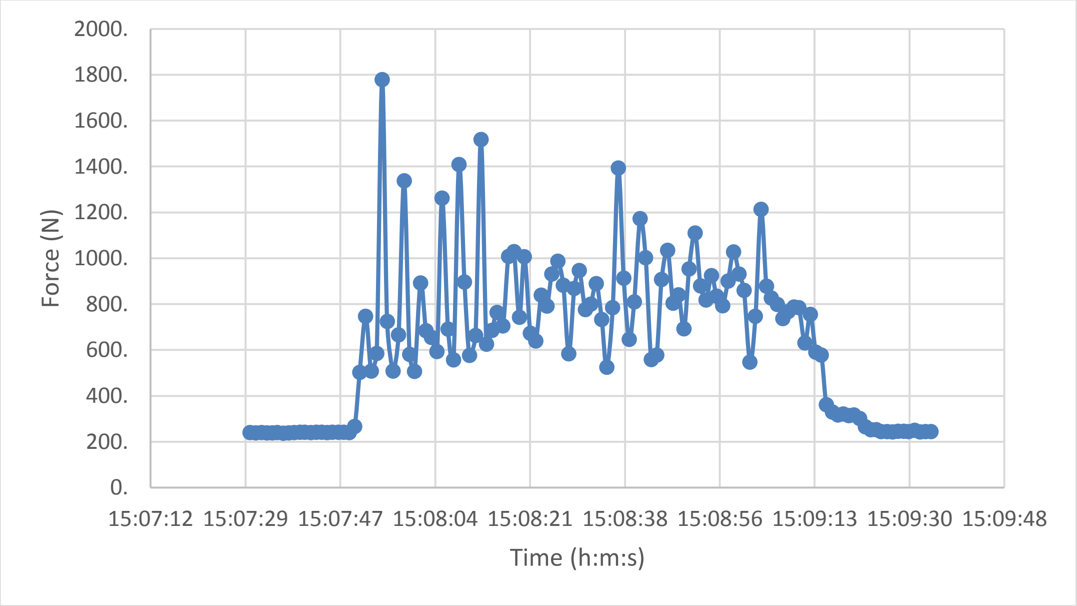

Figure 23- Graph of draft v. time, for run six .

Table 1 shows the average draft for each run of 50 meters, which is the average force measured by the load cell. It also shows the overall average, which is the average of all the data points across all 6 runs. Each run was performed with 63.5 kg (140 lb) of weight in the weight boxes. The variation in draft between each run can be explained by the variations in soil type and texture across the field. The variation in soil texture can produce a change in resistance and penetration depth as the unit is pulled along the row, leading to variations in draft. The overall average draft was determined to be 796 N (179 lbs). The average vertical component of the draft and the average horizontal component are also reported.

	Run 1 (N)	Run 2 (N)	Run 3 (N)	Run 4 (N)	Run 5 (N))	Run 6 (N)
Average	862.9	702.8	769.5	791.7	796.2	836.2
Max	1289.9	1232.1	1894.8	1281.1	1427.8	1774.6
Min	569.3	400.3	458.1	471.5	382.5	493.7
Average Vertical Component	250.0	238.0	266.0	246.0	237.0	241.0
Average Horizontal Component	825.9	661.3	722.1	752.5	760.1	800.7
Overall Average	796.0					

Table 1: Average, Maximum and Minimum Draft for Six Runs.

Seed Placement and Density

Figures 24 and 25 show the distribution of seed placement in terms of both spacing and depth. This type of plot is used for simultaneous viewing of distribution of seed depth (y-axis) and distribution of seed spacing (x-axis). Based on these graphs and field observations, it is apparent that the right-row seeding unit consistently performed worse in seed spacing than the left-row unit. While both figures show a relatively normal distribution around the desired seed depth of 2 cm, the left-row unit had had a more even distribution around a spacing of 10 cm. whereas the right-row unit had a left-skewed distribution, indicating that it produced more multiple seedings than the left-row unit did. It is believed that this poor performance is due to a worn mechanism inside the seed hopper, possibly the brush. For this reason only data from the left row were used to determine whether the prototype worked as desired.

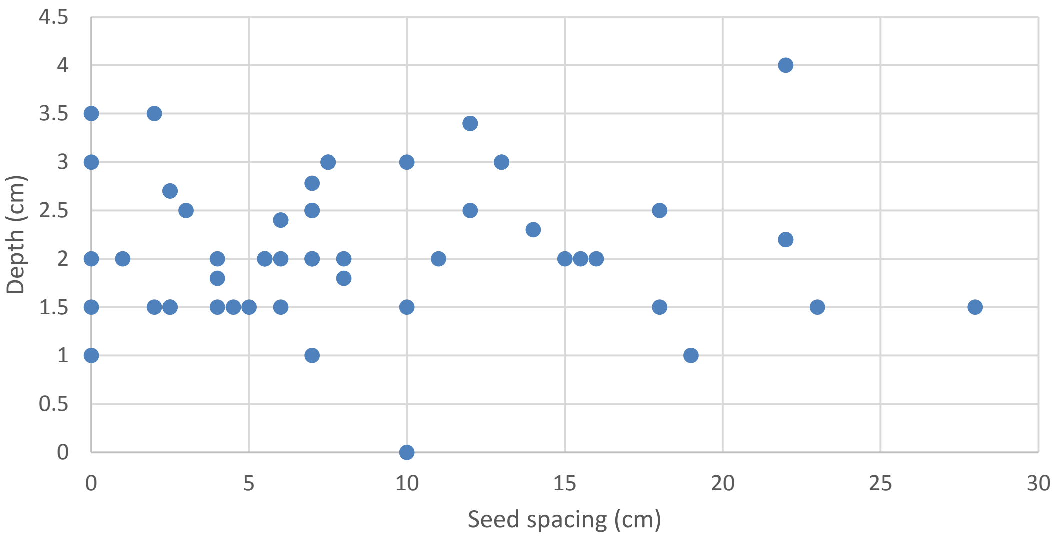

Figure 24: Graph of Seed Spacing & Depth for Left Seed Hopper for Runs 1-6.

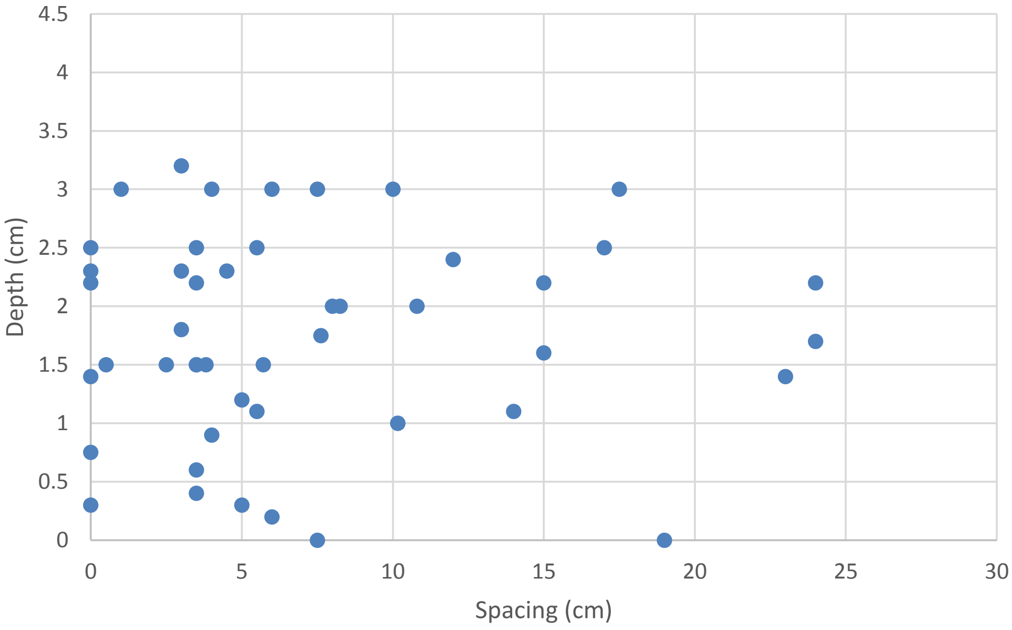

Figure 25- Graph of Seed Spacing v Depth for the Right Row for runs 1,4,5,6.

The average number of seeds found in each 1.0-m section of the left row was determined to be 9.3, which compares well to the target value of 10 seeds/m. There was a maximum of 14 seeds per meter of row, and a minimum of 6 seeds per meter of row. This range seems to be high, but not much information has been reported in the literature on the number of seeds per meter for most planters. Most reports focus on the seed spacing, which is dealt with below.

Table 2 shows the average seeding depth for each run. Prior studies have shown that a variation of 25% is common for a double disk with a rear press wheel (Karayel and Ozmerzi, 2008). Using this level of variation about an expected depth of 2.0 cm, there is an expected seed placement depth range of 1.5 to 2.5 cm. Table 2 shows that three of the runs are within that range, and two of the three that are outside of the target range by less than 2 mm. Considering that error in these manual measurements is significant, in relation to seed depth placement this prototype is within a reasonable standard for gravity-fed double-disk systems with a press wheel.

Average seeding depth (cm)						
	Run1	Run2	Run3	Run4	Run5	Run6
left row	2.1	2.13	1.75	1.25	2.69	2.65

Table 2- Seed Depth for Each Run of Left Seeder Unit.

Table 3 shows the spacing between seeds in the 1.0-m section of each row that was uncovered. Based on Table 3 and Figure 24, the seeds can be categorized into three groups (Karayel and Ozmerzi, 2002): 1) quality feed index (QFI), which includes seed spacings that fall within the range of 5 to 15 cm (the goal is 10 cm ±50%); 2) multiple index, which includes seed spacing's closer together than 5 cm; and 3) miss index, which includes spacings farther apart than 15 cm. Based on these classifications it was found that, over all six runs there was a QFI of 57.2%, a miss index of 16.0% and a multiple index of 26.8%. The QFI has been reported for other seeding units is in the range of 45% to 85% (Bracy and Parish, 1998), indicating that the QFI found here is on the low end of what is desirable. The miss index is high but is still comparable to the reported seeders (15% to 39%). The multiple index is less often reported, but it is also high compared to what has been reported. All measures of seed spacing might be improved by using new seed hopper units or repairing the internal parts of the current ones.

Left row seed spacing (cm)														
Run 1	0	2	22	7	14	4	4.5	2.5	2	8	4	5	4	15
Run 2	0	5.5	7	18	7	12	11	1	2.5	6				
Run 3	0	16	3	15.5	10	7	6	19						
Run 4	0	23	8	18	28	10								
Run 5	0	10	7.5	7	6	5.5	2.5	22	13	3.4				
Run 6	0	10	7.5	7	6	5.5	2.5	22	13	12				

Table 3- Seed Spacing for Each Run of the Left Seeder Unit.

Press Wheels

The original press wheel design was rated as good for ensuring seed to soil contact. However the prototype’s configuration during turnarounds at the end of a row applied a sideways force on the press wheels. This force damaged the press wheels, resulting in poor performance. The modified press wheels were judged in the same manner and were rated as average for ensuring seed to soil contact. The single press wheel did not place as much soil on top of the seeds on average as the original double press wheel did. However, it did do a better job of compacting the soil around the seeds.

Residue Managers

The residue managers were rated as sufficient for light residue, meaning that they moved 20% or more of the residue from the path of the furrow openers. Because the straw was not lying in a uniform direction, it was difficult for the residue managers to move a large amount of the residue away from the furrow, resulting in some of the residue being pressed down into the soil with the seeds, possibly causing less seed-to-soil contact. In areas where the residue was not as dense, the residue managers performed better. The residue managers also seemed to serve the purpose of breaking any crust that might be on the surface of the soil without pulverizing the soil structure. This action is achieved as the tines are pushed a short distance into the soil at regular intervals as the planter rolls forward and then are pushed out at an angle, breaking the crust.

CONCLUSION

In the final configuration the prototype planter design met all of the design criteria. The refined prototype functioned well as intended. It had a low average draft of 796 N (179 lbs) . The seeding rate for the prototype was 9.3 seeds per meter, which is acceptably close to the 10-seed/m target rate. The planter had a QFI of 57.2%, a miss index of 16% and a multiple index of 26.8%. These values are at the low end of desirability, yet they are within the expected ranges. The residue managers were rated as sufficient for light residue. The press wheels were rated as good for both configurations, but the final configurations is preferred because of its sturdiness when turning the planter around.

Practical Implications

This research project demonstrates that it is possible to manufacture a no-till planter in areas where large modern manufacturing facilities do not exist, such as small cities in rural areas of South Africa. The prototype planter's average draft force of 796 N (179 lb) indicates that the combined weight of the draft animals would need to be between 579.7 and 811.9 kg (1278 and 1790 lb) to pull the prototype for an 8-h work day. The oxen observed at Ukulima Farm in South Africa weighed roughly 771 kg (1700 lb) each, while donkeys can commonly weigh 275 kg (600 lb) (San Diego Zoo, 2014).

Thus, two large donkeys or small oxen could pull the prototype planter for a full 8-h work day.

The parts for this prototype would cost roughly $1000 (USD) if several units were produced at the same time. The prototype is constructed such that it can be built in almost any machine shop in the world that has power and basic powered fabrication tools. Producing this implement in rural towns in South Africa would make it more widely available to the target audience, making it more likely to have a positive impact on the lives of small farm holders. Also, repairs could be easily performed by the people who constructed the implement, which could reduce cost of repairs over having to ship the implement to another town.

This design has benefits over current models that are available. First, it employs conservation tillage, reducing the need for traditional tillage methods such as the moldboard plow. The prototype is a two-row planter that would cost roughly the same as the Piket Implements single-row planter currently produced in South Africa. It has lower draft than the modified Fitarelli brand two-row model used at the Ukulima research farm, which was reported to have an average draft of 1605.7 N (361 lb) for high residue and 1165.4 N (262 lb) for low residue (Roosenberg, 2011). Thus, the prototype appears to be more practical for a wider range of small farm holders. This implement is also robust and easy to maneuver. It is balanced so that a single person can pick it up at the tongue and hitch it to the draft animals, and then be able to drive the oxen and operate the implement with a minimum amount of maneuvering around the implement.

Future Work

The prototype planter described does not present either an optimized design or a production design. Research should be performed in the following areas. (1) Accurately measuring the force applied to each frame member should be done in order to optimize the design for production. (2) Designing or selecting a seed hopper that works better with the design of the planter is critical. While the seed hopper system functions as currently constructed, it still needs refinement. The prototype planter included hoppers from a Case-IH 900 planter, a model no longer in production, making parts hard to find. The hoppers are also larger than needed, and the seed plates are difficult to change. While they were useful for testing purposes, they are not practical for a production model. The current seed hoppers use a gravity-fed, gear-driven plate system. It would take little effort to remove them and retrofit mounting methods to use another gravity-fed, plate-driven model. The mounting should be simplified, the seed plates should be simple to change, and there should be a number of different seed-plate options to accommodate different crops common to both production and subsistence farmers. Making some or all of these enhancements would likely improve the seeding indices and produce better crops. (3) With respect to the residue managers, increasing the number of tines on each wheel might increase their effectiveness in heavier residue. Also, investigating different residue amounts and types is important to evaluate and improve the residue managers. It has been suggested that a coulter disk would be a helpful addition for cutting through heavy residue. (4) Determining the amount of weight needed in each weight box to achieve a desired seed depth placement in a particular type of soil would be helpful for utilization of the planter. Doing so would relieve the farmers of using trial-and-error methods to determine how much weight would be needed to plant the crop.

Much of the work of farming fits into two categories, planting and cultivating. For use with animal traction there is a distinct lack of machines for either of these functions available in South Africa, and probably also many other areas of the developing world. This thesis lays out a design for a no-till planter that can fill a void in planting. An animal-powered cultivation machine could be developed to fill another major void. Cultivation takes a large amount of time and effort for small farm holders. Developing a cultivation machine that is animal powered and compliments the conservation tillage techniques incorporated into this prototype planter would reduce the work load of small farm holders while improving production methods and results.

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