Design, Development and Performance Evaluation of Two Wheel Tractor Drawn One Row Potato Digger

Teka Abreha Gebru

A Thesis Submitted to the Department of Mechanical Systems and Vehicle Engineering, School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfilment of the Requirement for the Degree of Master's in Agricultural Machinery Engineering.

Office of Graduate Studies

Adama Science and Technology University

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Adama, Ethiopia

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Amana Wako (Phd)

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DECLARTION

I hereby declare that this Master Thesis entitled “**Design, Development And Performance Evaluation Of Two Wheel Tractor Drawn One Row Potato Digger**" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Design, Development And Performance Evaluation Of Two Wheel Tractor Drawn One Row Potato Digger**" prepared under my guidance **Teka Abraha Gebru** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Agricultural machinery engineering.

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

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APPROVAL PAGE OF M.Sc. THESIS

I, the advisor of the thesis entitled "**Design, Development and Performance Evaluation of Two Wheel Tractor Drawn One Row Potato Digger**" and developed by **Teka Abreha Gebru**, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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We, the undersigned, members of the Board of Examiners of the thesis by **Teka Abreha Gebru** have read and evaluated the thesis entitled "**Design, Development and Performance Evaluation of Two Wheel Tractor Drawn One Row Potato Digger**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Agriculture Machinery Engineering.

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External Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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ACRONYMES

ASME	America Society of Mechanical Engineers
BHP	break horse power
CATIA V5	Catia version five
CSA	Central Statistical Authority
DBHP	Drough bar horse power
ETB	Ethiopian birr
Fc	Field capacity
GO	Governmental organization
MAMRERC	Mekelle Agricultural Mechanization And Rural Energy Research Center
MS	Mild steel
NGO	Nongovernmental organization
2WT	Two wheel tractor
US	United state
ROD	Ridge opening device
OPL	An Ox-drawn potato lifter

ABSTRACT

Ethiopia has the highest potential for potato production than any country in Africa with 70% of the 13.5 million ha of arable land suitable for potato cultivation. Potato harvesting in Ethiopia has been accomplished by hand using a hoe and fork digger leading low yield of potato per hectare. The most strenuous and backbreaking task is digging the tubers using a hand tool such as a hoe and fork, followed by manual collection. Therefore, this study aimed to develop a two-wheel tractor-drawn one-row potato digger for harvesting potatoes as well as separating and transporting them over soil surface with minimum losses and mechanical damage. The digger encompasses the support frame, blade, separating unit (apron), Transmission system (belt, pulley, cam, arm, and shaft), and fifteen-horse power two-wheel tractor. Physical properties of potato seed were investigated to optimize the design of the components of the digger. Every component of the digger was designed using catiav5 software. The materials used for the fabrication of various components were selected considering their function and strength requirements. The prototype was fabricated and assembled in the Mekelle agricultural mechanization of a research center. The developed digger was tested at three levels of forwarding speeds (1.4, 2, and 2.5 km/h) in sandy loam soil. The theoretical field capacity, effective field capacity, field efficiency, percent losses, and percent damage at 1.4 km/hr were 0.19 ha/hr, 0.162 ha/hr, 85.26%, 8%, and 5.3% respectively. The result showed that the sphericity of seed, mean percent of undug potato, and percent of potato seed damage were 88.38%, 8%, and 5.3% respectively. The field test was conducted at speeds of 1.4, 2, and 2.5 km/h speed on sandy loam soil and shows good digging performance but 1.4 km/h speed gave better operation results than other operating speeds. The cost of fabrication for the development of the potato digger was 29073.43 ETB. According to the performance evaluation results, it is concluded that the prototype harvester was easy, efficient, and affordable by potato-producing farmers of the Tigray region.

Key Words: Potato Digger, design, Separating Unit, Potato

CHAPTER ONE

1. INTRODUCTION

1.1. BACK GROUND

Potato is the most common name for a perennial plant **Solanum*Tuberosum*,** of the family **Solanaceae,** and is popularly known as the "King of Vegetables". It is the most important food crop. Being a short-duration crop, it produces more quantity of dry, edible energy and protein in a lesser duration of time than cereals like rice and wheat. It is a major crop grown in more than 100 countries in the world. Spanish explorers are believed to have brought it in the 16th century from Paris to Spain. Hence, potatoes may prove to be a useful tool to achieve the nutritional security. Knowledge interventions are important for any production system for higher yields and make it cost-effective (Malik *et al.*, 2017).

In Ethiopia, potato plays an important role in improving food security and cash income of smallholder potato growers due to its high yield potential per hectare and nutritious tuber. Around 1,288,146 households are dependent on potato production and about 67,361.87 ha of land is under potato production, which has 31.13% area coverage among root crops (CSA, 2015). Potato is grown in four major areas in Ethiopia: the central, the eastern, the northwestern, and the southern regions. Together, these areas cover approximately 83% of the potato farmers (CSA, 2009). The climatic condition, in Ethiopia, is suitable for the production of high-quality ware and seed potatoes with the potential to grow in 70% of the 10 million ha of arable land in the country (FAO, 2008). Potato production can be increased through an increase in area coverage and productivity. Currently, only 2% of the potential area in Ethiopia is under potato production and the average productivity of potatoes is less than 10,000 kg.ha-1 (Adane et al., 2015).

The agriculture system in Tigray has been mainly cereal-based. There have been various efforts to increase the productivity and quality of horticultural crops produced in the region. Moreover, many new horticultural crops were being introduced by different governmental and non-governmental organizations. However, the productivity and quality of these crops have not been optimum due to various problems, including the indiscriminate introduction of planting materials, improper disease and pest management, suboptimal production practices, as well as lack of good quality planting materials (Hailemariam *et al.*, 2003).

Potato has been one of the important crops in Tigray for the last several years. The agro-climatic conditions of the region particularly the eastern, southern, and central zones are ideally suitable for good quality potato production. The eastern and southern zones are particularly the highest potato producer, which accounts for more than 83% of the total area covered by potato and more than 74% of the total potato production of the region. Potato is cultivated in nearly 575 ha with an average yield of 10 t/ha. It is grown during the belg and meher seasons in Tigray (Hailemariam *et al.*, 2003).

Increased mechanization was one of the most influential factors in the ability to expand potato production and minimize the production cost, thus increasing the net income for potato producers. In practice, in mechanical harvesting, potato tubers are primarily affected by the apparent damage caused in potato roots and undug crops. To mitigate these issues, potato harvesters have been modified to prevent damage to potato crops (by, for example, altering the belt speed, cam amplitude, or blade tilt angle, and digging depth). Thus, to assess the extent and type of potato tuber damage during the mechanical harvesting process, the performance of a one-row potato digger was examined. Empirical evidence indicates that numerous studies have evaluated the developments in potato harvesting mechanization. In addition, potato harvester performance was assessed with an emphasis on minimizing potato tuber damage. However, there is an evident paucity of research on the variables affecting harvester performance that are examined in the present study (Al-Dosary, 2016).

The lack of a suitable mechanical harvester for root crops is due to a number of factors such as the geometry of tubers in the soil at maturity, soil conditions, and the high draught requirement of machines (Younus *et.a*l., 2015).

With the advancement of agricultural mechanization, the use of agricultural machinery is widely increased. For the power, transmission from the power source to the machinery V-belt is mostly used in many agricultural types of machinery such as power tiller, tractor, combine harvester, reaper, seeding machines, thresher, pump, winnowing machines, huller mills, etc. V-belt has diversified use due to its distinct advantages that, it absorbs vibration and shock, tending to transmit only a minimum to the connected shaft, it is quiet if properly maintained it can be designed to have a long trouble-free life (Billah *et.al.*, 2008).

1.2 Statement of the problem

There are several challenges faced by the farmers along with potato production. Most significant is the high perishability of the crop and the lack of suitable harvesting facilities to extend the shelf life of the potato. Producers lack appropriate harvesting techniques like the use of rudimentary tools like hand hoes and sticks for harvesting. It is the stable crop Tigray in the region and Ethiopia at large. A long time ago, the farming community has been cultivating and harvesting potatoes using human and animal power, which is a traditional and dated back farming system. The main problem observed in the case of the manual harvester is, it requires intensive labor, tedious and time-consuming operation. Farmers had been encountered a shortage of labor, especially, during a pick harvesting season. Potato has a high perishability crop, it needs appropriate harvesting techniques, to prolong its Shelf life. These problems will be continued unless this scenario would be changed. To alleviate the aforementioned problem, the design and development of a two-wheel tractor-drawn one-row potato digger, which improves potato quality, reduces time consumption, and traditional farm operation, to make it easy for forming community is crucial.

1.3. Objective of the study

1.3.1. General objective

The general objective of this study was to design, develop and perform an Evaluation of a two-wheel tractor drawn single row potato digger, which has the capability of digging potato with minimum damage.

1.3.2. Specific objective

The specific objectives of the study were:

- To determine the physical property of the potato crop.
- To design and develop of two-wheel tractor-drawn one-row potato digger.
- To evaluate the performance of a 2WT drawn one-row potato digger.
- To select some components
- To design components using CATIA V5 software

1.4. Significance of the study

In Ethiopia, about 70% of smallholder farmers own farmlands less than or equal to one hectare in size and the average grain yield for the various crop is less than one metric ton per hectare (CSA, 2013). It is very difficult for these farmers to own and operate costly harvester equipment that can establish the optimum plant population. In the Ethiopian farming system, farmers are working manually and using animals for farm tasks. Harvesting potatoes in Atsbiwomberta wereda, in particular, is constrained by several factors such as the perishable nature of the product, bulkiness, time-consuming, and timeliness cost. The cost of animals for operation is becoming higher as compared to mechanical potato harvesters. Therefore, farmers can benefit when they buy or rent the Two-wheel tractor, it can perform for other agricultural farm activities such as planting potato, seedbed preparation, fertilizer application, harvesting especially under upland crop condition, irrigation purpose, transportation agricultural product and threshing, chopping, and other stationary farm operation. Farmers have more benefited in terms of time-saving and timeliness costs when they use a two-wheel tractor drawn one-row potato digger. The primary significance of the study is to all actors in the potato producers. This technology has a significant contribution to the development of potato production by increase, more land into production, provide a better quality of work, reduce drudgery in farming activities, enhancing lifestyles, improve the efficiency of farm operations and quality of the crop, improve the value of work, produce and processed products, provide employment opportunity and sustainable rural livelihoods.

1.5. Scope of study

The research was narrowed down to concentrate on the production area (atsbiwemberta woreda) and the types of crops were limited to potatoes for their increasing pick harvesting season problem they used to face. The scope of this study was also encompassed designing, development, and testing of a 2WT drawn one-row potato digger. By selecting, identifying, and specifying the size, type, and its different part specification, on the design of the digger and the reason for the selection of these different components, dimension and shape of each part during the design time. After the decision on how to design and identifying the type and shape of the digger, material cost, the construction of the digger components, and the performance of the prototype were estimated.

CHAPTER TWO

2. LITERATURE REVIEW

The harvesting potato crop is a critical part of the entire potato production and marketing operation. Crop yield and quality cannot be increased during harvest, but they can be decreased, sometimes drastically. So harvesting operation is a highly important practice that we should pay attention to, and the main purpose of it is harvesting potato on time with minimum damage and cost. As the production of the potato crop is increasing, the design and development of potato diggers have become an issue for many researchers nowadays. Most Ethiopian farmers still using the method of traditional harvesting of potatoes by hoe, spade, and other hand tools. The traditional potato harvesting method is not suitable in terms of saving human power and time. Product and productivity are less and less. This way of harvesting method of potato causes low yield production. The design and development of potato diggers have become an issue of many researchers now in Ethiopia. A machine separates potatoes from the soil. The vibration reaches relative separation speed but causes less damage to the potato (Ganesh *et al*., 2019).

Mohamed *et al*.(2019) developed a Mini-tractor-driven Coleus digger. A mini power tiller operated coleus harvester was field-tested and performance was evaluated. However, it had several disadvantages associated with its construction. This was because it used a rotary slasher, which created excessive vibration. This caused the tubers to scatter in the field, which was inconvenient for the farmers to collect. In addition, it caused damage to the coleus and thus yield was reduced. The digger consisted of a frame, share, finger assembly, cam drive and connecting rods, and a drive unit. The width of operation and the other size and shape of the components were determined. The field-testing of the digger was conducted to find out the time of operation, fuel consumption, and harvesting capacity with respect to operating speed and depth of operation. The results for different levels of the parameters were analyzed. The performance of damage and field capacity were also determined.

Sukhwinder (2006) tested two-row mounted type and suitable for medium horsepower (30-40 hp) tractors, which are most popular among the farmers. Digger was field-tested in moist as well as dry field conditions at different forward speeds of operation at two row spacing of 610 mm 686 mm. Exposed and unexposed potatoes Lifting time and tuber damage were lifted manually and weighed. Collection recorded in two-meter long strips time recorded at five places. Effect of forwarding speed: As evident exposure, percentage of tubers in multipurpose digger improved with increase forward speed and was maximum (84.5%) digger. This may be due to less clod formation crop, 610 mm row spacing) as affected by the speed of operation resulting from high-speed impact in Forwarding speed Exposure damage multipurpose digger. Under dry field conditions, the draft requirement is more. At 4.5 km/h. This may be because of increased speed, rolling of tubers is Performance in early crop enhanced due to severe shaking of ridge soil. Multipurpose digger performed well in There was little effect of speed variation on early crop and covered an area of 0.13 ha/h.2.1 Methods of potato harvesting

2.1. Methode of harvesting

2.1.1. Manual harvesting

This is the traditional method of harvesting root crops using a hoe, cutlass, or mattock to dig around the standing stem to pull out the root before detaching the uprooted roots from the base of the plant.

Figure 2. 1. Manual harvesting

2.1.2. Semi manual harvesting

An Ox-drawn potato lifter (OPL) was designed based on the groundnut digger and the ordinary ox-plow. The digger is similar to a moldboard plow. It consists of a mild steel box frame, a bent tine for attaching moldboard with the frame, moldboard plow-shaped part, and a flat piece attached to the tip of the share, hitch assembly, and handle. For operation, a pair of bullocks pull the implement; the flat piece attached to the share tip penetrates in the soil and harvested crops along with the soil lumps slide over the moldboard.

Figure 2. 2. Semi manual harvesting of potato

2.1.3. Mechanical harvesting

Mechanical harvesting of taproot vegetables involves the use of harvesting implements integrally hitched to a tractor to uproot the rooted vegetables. Manual effort is however required after the uprooting has been completed to collect and detach the root tubers. The following field requirements/conditions are also necessary to allow for an optimum mechanical taproot harvesting operation field free from hidden obstructions (rocks, roots, stumps, etc. down to 40 cm deep) of sizes that can interfere with lifting the tubers; good weed control as weeds block the lifters (Ganesh *et al.*, 2019).

2.1.4. Potato harvesting stages

Stage 1. Potato foliage and stalks need to be removed before harvesting to prevent blight infection of the tubers and to facilitate the passage of the harvester. Burning off also removes any weeds, which would interfere with the working of the harvester.

Stage 2 . Elevating potato tubers from the soil is called digging.

Stage 3. The development of mechanisms to separate potatoes from stones and clods has been directed towards mechanical devices located on the harvesters.

Stage 4. Collecting potato from the surface handily by laborers.

2.2. Physical Property

Ahangarnezhad et al. (2019) determined the physical properties of Potato, 100 potato samples were randomly selected and handpicked to undergo experiments. The samples were kept in cold storage at 4°C before the test. The mass of samples was determined with an electronic balance with 0.01 g of sensitivity. To determine the average size of the potatoes, three linear dimensions, namely the length (*L*, mm), width (*W*, mm), and thickness (*T*), were measured by using a digital caliper with an accuracy of 0.01 mm. the geometric mean diameter and the arithmetic mean diameter was calculated. Based on the result, the mean length, width, and thickness, arithmetic mean diameter, sphericity, project area, were 91.23 mm, 63.17 mm, 52.43 mm, 66.85 mm, 68.94 mm, and 74.09% respectively. The results showed that the length is not significantly different from the width and thickness, so it can be concluded that the potato has high sphericity equal to 74.09. The volume and area of the product are applied in the modeling matters and heat transfer during the drying or freezing processes.

Singh *et al*. (2006) determines the physical property of two potato varieties. The size of the tuber was determined by measuring the dimensions of the principal axes, i.e., a, b, and c. Thirty pieces of whole tubers were randomly selected and their dimensions were measured with the help of a Vernier caliper. The average values of a, b, and c which are length, major diameter, and minor diameters of the potato respectively for the two varieties, were found to be 5.768, 4.661, and 3.777 cm for the first one and, 4.268, 3.904, and 3.023 cm, for the second varieties.

Gamea et al. (2020) A digital slide caliper of the accuracy of 0.01mm was used for measuring the three axes of tuber (the major axis as tuber length (L-mm), the intermediate diameter as tuber width (D-mm), and the thickness of tuber (T-mm)). The weights of tubers were conducted using an electrical digital balance model with a maximum capacity of 3200 grams and 0.01-gram accuracy.

2.3. Design consideration

Sukhwinder (2006) designed multipurpose two-row potato digger suitable for medium horsepower (30-40 hp) tractors, which were most popular among the farmers. The three-point hitch system is of standard size and shape. Flat iron columns were welded on the blade in such a way that blade is inclined to the ground at an angle of 21° when the column is vertical. The blade was wide and jig-jag shaped at front. It was made of angle iron at the rear bottom to increase its strength against bending. It had Two ridge opening devices (ROD) that were bolted through opener bases at a spacing of either 610 mm or 686 mm. In front of the RODs, there are high carbon steel shovels. The designed digger mainly consists of the following parts.

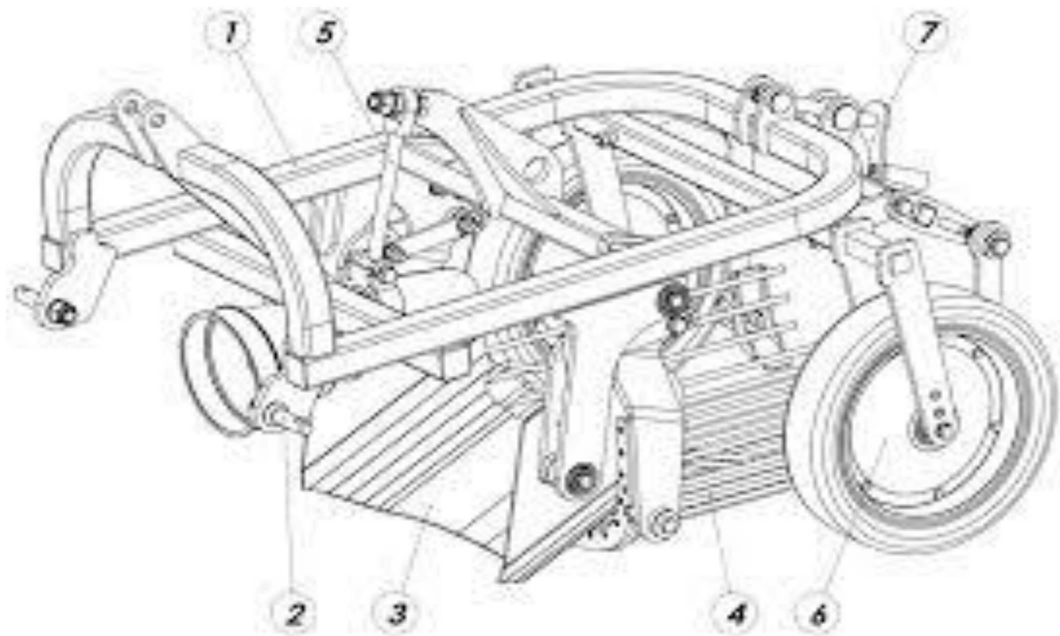

Figure 2. 3. parts of the potato digger

1. Frame
2. Camshaft
3. Blade shovel
4. Sparating fingers
5. follower
6. Ground wheel
7. Depth adjustment

Younis *et al*. (2006) developed a potato digger by adding a new reciprocated device to vibrate the blades. The modification was performed in one of the local workshops in Cairo. Meanwhile, the field experiments were carried out in Nobaria city. The vibrating system consists of three sub-systems; beam holder, vibrating device, and vibrating transmission system. The vibrating device consists of three parts; reciprocating ruler, cam, and driving arm. The cam transmits the motion to the reciprocating ruler by a driving arm (follower) that was designed to produce the proper amplitudes.

Liu et al. (2009) designed single-row potato harvester with some new features. For example, it has an adjustable digger blade angle, flexible guiding supporting wheels of the lifting chain that could move upward with the support of a cantilever plate.

Zhang et al. (2014) designed the vibrating potato digger. With a grid digging device and an eccentric rocker vibrating digging mechanism, this machine could perform potato digging and harvest in different profound adjustments with a screw-type blade.

Dagnnet Amare (2015) considered Potato (Solanum tuberosum L.) is the fourth most important food crop in the world. It provides high nutrition and is an adaptive species for climate change. Potatoes use less water per nutritional output than all other major food sources and can be grown across Africa. The potato provides more food per unit area than any other major staple crop. They are the perfect food and one of the few that can sustain life on their own. Thus, it has a significant impact on providing nutrition to families, increasing household incomes, and providing a surplus to the wider market.

Shirwal *et al.* (2015) developed tractor-mounted mechanical carrot harvester and consists of different component units. The desired functions of carrot harvester are to dig and lift the carrots from soil and separate soil mass from carrots and leave behind the harvester for collection with minimum crop damage. Thus, the basic components of the carrot harvester were the mainframe, digging unit, and soil separation unit. The mainframe of the carrot harvester was developed to attach the digging unit and soil separation unit with a tractor three-point linkage hitch system. It was fabricated from mild steel square pipe. The digging unit consists of a blade, which digs carrot with soil mass, lifts it, and transfers it to the soil separation unit. A 'V-Shaped' digging blade was designed based on the draft acting on it while harvesting of carrot. Draft on the blade while harvesting could be determined theoretically by using blade dimensions and soil and operational variables. The working depth of the blade was mainly dependent upon the length of the carrots. The soil-separating unit was attached just behind the blade to receive the dugout carrot and soil mass.

2.4. Performance Evaluation of Tractor Drawn Potato Digger

Kumar (2017) evaluated tractor drawn potato digger cum – elevator, tested at speeds of 1000, 1200, 1400 rpm and depth of Cut 50, 75, 100 mm. The shape of the field for trial was rectangular having an area of about 3150 m^2. The soil moisture was measured on dry basis, which was adequate for digging not stick to the potatoes.

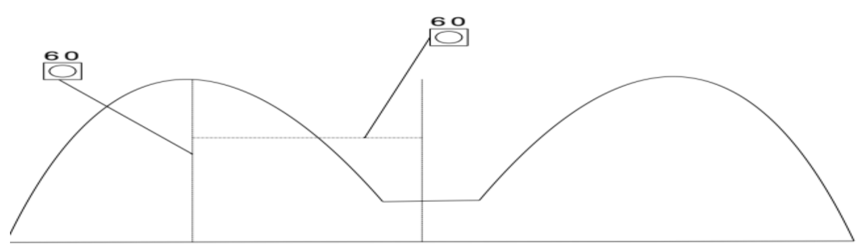

Figure 2. 4. Cross sectional view of Ridge

The digger was found to perform very well under varying soil condition. Very little mechanical injury of the tubers was observed of two types. These cut tubers and skinned tubers. The percentage of cut tubers damage was based on the total weight and number of tubers in each sample. It is evident that with the increase in forward speed the skinning damage also increases up to 4%. On studying, the average percentage of severely damaged tubers was 3.2%. This is considerably lower than the damage level of the commercial harvesters. It results in 4-5 reduction in harvesting losses. Field capacity, fuel consumption, cost of operation and crop damage was measured.

Shirwal et al. (2015) Developed carrot harvester that contains frame, blade and rod type separator**.** The soil-separating unit was attached just behind the blade to receive the dugout carrot and soil mass. To separate the soil from carrots, the rods are arranged in length wise along the line of travel of the harvester. The incoming crop and soil-mass was allowed to distribute by increasing the width of the separator gradually at an angle of 45º. The spacing between the rods was kept in the range such that the carrots should not fall from this space. By the study of biometric characteristics of the carrots the diameter of the carrots are found in the range of 316 to 480 mm, it was obtained no fall of carrots through that spacing. Specifications of major components were decided based on the design of the blade and soil separation unit. Digging blade and soil separator were attached to the side supporting flats and then the whole assembly was attached to mainframe. Thus, complete unit of single unit carrot harvester was developed.

Narender *et al.* (2019) done on Optimization of Performance Parameters of Root Crop Digger for Potato Crop. Nine performance parameters were determined to evaluate the root drop digger.
The exposed potato was calculated to know how efficiently the oscillating conveyor was able to separate the potato from soil. He was able to calculate the undug potato, bruised potato, cut potato, digging efficiency, field capacity and field Efficiencies. The percent of exposed potatoes, undug potatoes and cut potatoes increased with increase in forward speed of root crop digger but the digging efficiency decreased with increase in speed. The percent of exposed potatoes, undug potatoes, cut potatoes decreased with increase in blade angle of root crop digger. Nevertheless, the digging efficiency increased with increase in blade angle of root crop digger so, the above study revealed that the forward speed 2.3 km/ h and blade angle of 23^0 is selected best for operation of the digger in the field for potato crop.

Younis et al. (2006) tested carrot digger. The tests of the digger were carried out in a sandy soil, with 147 hp tractor at four different forward speeds. The carrot harvester unit was evaluated for its performance parameters like percentage of carrot harvested, percentage of carrot damage, soil separation index, power requirement and field capacity. The bill of material of the carrot harvester was prepared along with estimated cost of fabrication and total cost of carrot harvester.

Azmoodeh *et al*. (2014) evaluated the walking tractor drawn peanut harvester. The studied factors for peanut harvester evaluation were two levels of soil moisture content and three levels of forward speed (1.7, 2.5 and 3.3 km/h). In order to comparing of mechanical and manual harvesting methods, it was necessary to specify the best operating condition and then, the lowest pods loss compare with manual harvesting. For this purpose, the field was divided into three different experimental plots. Two plots used for evaluation of peanut harvester and third were for manual harvesting. For each of moisture levels was carried out a complete randomized design with forward speed factor and three replications.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the study site

Mekelle is located around 780 kilometers north of the Ethiopian capital Addis Ababa, at a latitude and longitude of (13°29′N 39°28′E), with an elevation of 2084 meters above sea level. The mean annual rainfall in the area is 714 millimeters, which is a semi-arid area. The mean minimum temperature is 12.6°C and the mean maximum temperature is 26.7°C. The soil texture is sandy Loam. The fabrication of the prototype was carried out at MAMRERC and the performance testing was conducted at the eastern zone, Atsbi Wemberta wereda.

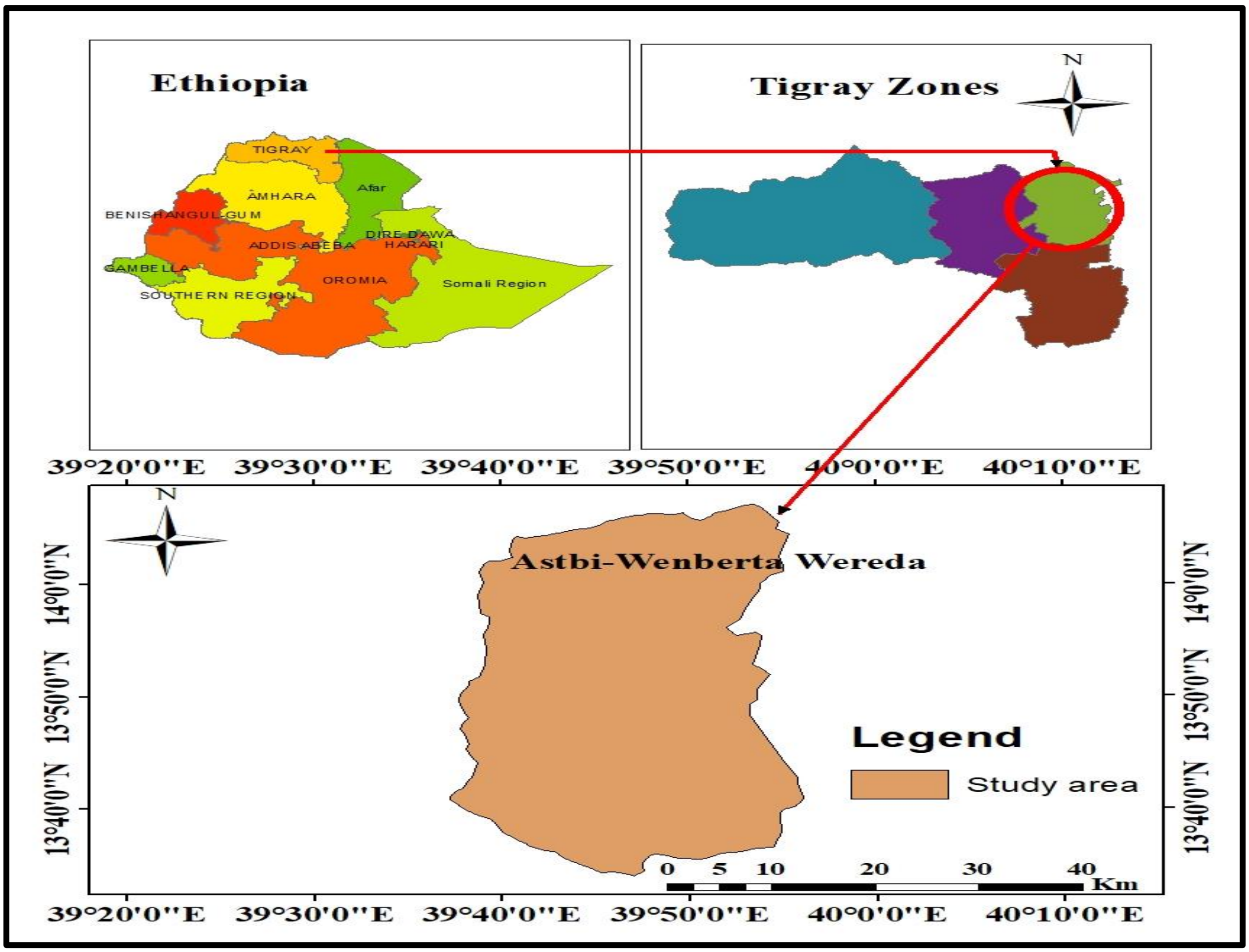

Figure 3. 1. Map of the study site

3.2. Materials Selection

Providing proper material for manufacturing components of potato digger is very important. It should be stiff, strong, wear resistant, and fulfill the operating requirements of different parts of the potato digger. The material should be good in terms of shape, weld, Machin able, easily available and should be locally available, suitable for fabrication, repair and maintenance by farmers or village artisans. Materials of the potato digger was selected based on design requirement. Materials such as digger blade, shaft, and pulley must be strong was selected based on durability, cost, availability, strength, rigidity, weight and friction. The materials for fabrication of various components were selected considering their function and strength requirements as given in Table:

Table 3. 1. Machine used and functions

S.N	Machine name	Function
1	Lathe machne	Threading /finishing /cutting
2	Drilling machine	Can drill different diameters of hole
3	Grinder machne	Cutting tool
4	Arc Welding machne	Welding the joints
5	meter tape machne	Measurement of linear distance
6	Vernier calipers	Measurement of the outer and inner diameter
7	Hammer machne	It can strike an object
8	Screwdriver machne	Tighten screw
9	Different size of keys	Tighten nut and bolt
10	Snip machne	Cutting sheet metal
11	File	Smooth rough edge
12	Bending	Can Bend the blade or other components indifferent angle
13	Manual cutter	Cutting the different metals

Table 3. 2 Material used

No	Component	Materials use	Size	Functional requirement
1	Cam Shaft	Round mild steel (MS)	0.3m Length and 0.03m Diameter	For transfer motion to the oscillating fingers
2	Cam	Mild steel	0.03m Eccentricity	Providing maximum frequency of vibration.
3	Frame	Mild steel	1.00mx0.5mx0.065m Length x width x height	To support the implement.
5	Blade	Sheet metal	0.60mX0.13mX0.006m	Used to dig out the bared potato.
6	Finger(rods)	Round rods Ms	0.01Diameter and 0.60m Length	Used to separate potato from soil.
7	Ground wheels	Flat iron	0.4m Dim and 4mm Thick	Used to support the load of the machine and for rotation
8	Bearings ,bolts and nuts		Different size	

3.3. Physical property of potato crop

Understanding of Physical and engineering property of potato is important factor for designing separating unit of the one row digger. Seed properties related to the design of one row potato digger were determined. The physical properties of potato seed are important for the design of two-wheel tractor drawn potato digger. The Parameters such as size, sphericity, surface area, and bulk density were considered. Five samples of potato seed were taken and measured their size using Verne caliper used for measuring three axis of tuber (the major axis as tuber length (L-mm), the intermediate diameter as tuber width (D-mm), and the thickness of tuber (T-mm)). The methods used for determination of physical properties are described as follows. The list size was taken from the group to design the soil separator to through the tuber to the rear side of the digger.

Figure 3. 2. Measuring potato size using caliper

(Mohsenin 1986) used the following equations to calculate, physical properties of the crop. Parameters such as size, sphericity, surface area, and bulk density was calculated as:

$$S = \sqrt[3]{(a \times b \times c)} \quad \text{......} 3.1$$

Where: S =Size of potato seed, mm

a =Length of the potato, mm

b= width of potato, mm

c= Thickness of potato seed, mm

3.4. Design Considerations

The design of prototype one row potato digger was designed to replace the traditional way of harvesting potato. It comprises blade, separator (oscillating apron), arm, reciprocating ruler, cam, frame and ground wheels. All components of the machine was design based on the principles of operations. The two-wheel tractor drawn one row potato digger was designed as a functional unit. The details mechanical parts were designed with due attention to give good functional rigidity for the design of machine. The following design factors that were taken into consideration. The assumption was made during the design of the machine.

- The servicing of fabricated machine components was considered.
- Physical properties of potato such as length, breadth and height were considered.
- The machine was constructed with local materials in order to replace damaged parts that are not expensive.

- Machine factors such as strength, stability, rigidity, and whole weight was calculated.
- The overall cost of the machine was considered based on the LCC of the machine throughout the design stage.

3.4.1. Functional requirement of potato

The two-wheel tractor drawn Potato digger should fulfill the following functional requirements:

- It was dig Potato seeds properly.
- It was separate the seed from the soil.
- It was expose out the potato on the ground
- Itd was not be damage the Potato see

3.4.2. Agronomic Requirement of Potato

According to agronomic researchers the digger should fulfilled the following data.

- Separator of the potato seed was easy to adjust.
- The digger should dig out seed from a depth of 12 cm below ground level.
- The row-to-row spacing should be 30 cm.
- Width of the ridge should be 60cm

3.5. Design of Two-wheel Tractor Drawn one Row Potato digger

3.5.1. Description of two-wheel tractor drawn potato digger

Different parts and their functions of Two wheel tractor drawn Potato digger were described in this section i.e. digger (blade), rod type separator (oscillating apron), (flat cam) and reciprocating ruler. The Potato digger was designed based on research conducted on Potato digger and studying the existing potato digger, a two-wheel tractor drawn Potato digger was designed. After the Potato digger was designed, the following functions were performed: to dig-out the Potato seed, to separate potato seed from soil (by oscillating) and to expose the seed on the ground. According to the separating mechanism, the developed prototype was evaluated under field conditions. The studied parameters were listed below.

a) Determination of physical engineering properties of Potato seeds influencing design value of separating unit.

b) Design, fabrication and laboratory testing of seed separator.

c) Performance evaluation of the digger

The two-wheel tractor drawn potato digger machine encompasses the following parts as shown in Fig 3.3.

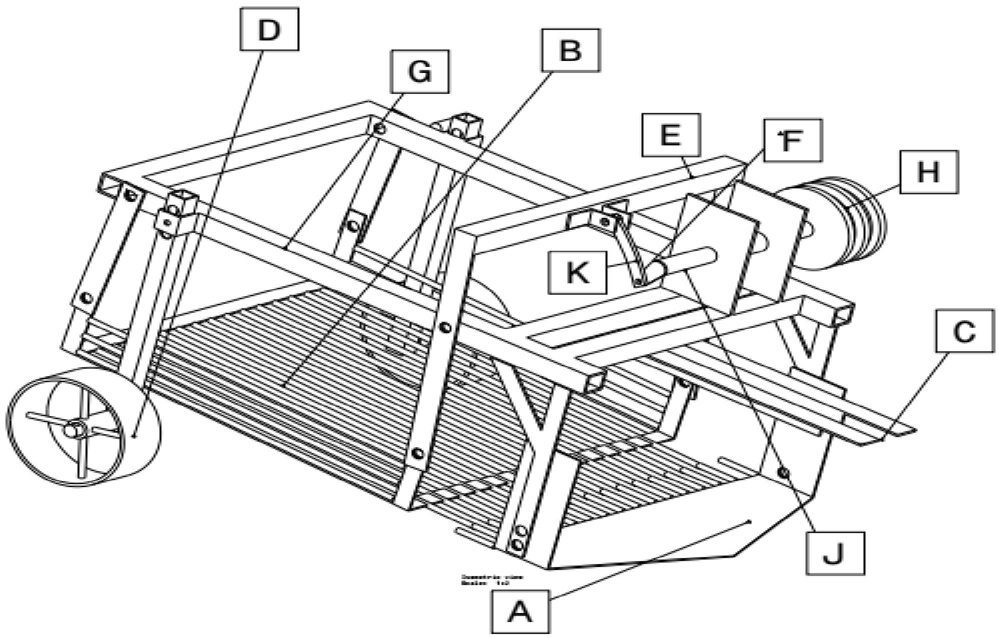

Figure 3. 3. Isometric view of theprototype

A. blade	F. offset position
B. separator or shaker	G. Frame
C. Draw bar	H. pulley
D. support wheel	k. arm
E. reciprocating ruler	J. shaft

In the design of two-wheel tractor drawn one row Potato digger it was considered the required horsepower and draft force. To design the digger first working width of the implement, Draw bar horsepower, break horsepower and draft force was calculated. According to Sharma (2010) the following equations was calculated.

Draw bar horsepower, (DBHP) = 60 % of BHP and The available horsepower of a two-wheel tractor is 15 hp.

$$DBHP=60\ \% \times (BHP) \qquad \ldots 3.2$$

$$draft(N)=\frac{DBHP\ (hp)\times 746}{3.6\times speed(m/s)} \qquad \ldots 3.3$$

Speed of the power tiller for digging the potato is 1.4km/h. putting this value in the following equation.

3.5.2. Weight determination of components of the digger

Weight of all component parts of the two-wheel tractor drawn Potato digger was calculated. To estimate the load of the prototype. Based on that weight of blade, separator (oscillator) reciprocating ruler (angle iron), shaft, hallow pipe (aluminum), frame, steel wheel, sheet metal, pulley and flat iron in the Potato digger were estimated using appropriate equations.

3.5.2.1. Weight determination of digger frame

Frame contains squire pipe size of (3320 mm × 40 mm ×4 mm), circular pipe, sheet metal size (200 mm × 130 mm × 6 mm), angle iron size (1060 mm, 40 mm×4mm), and flat iron (970 mm × 30 mm× 3 mm) as length, width and thickness respectively.

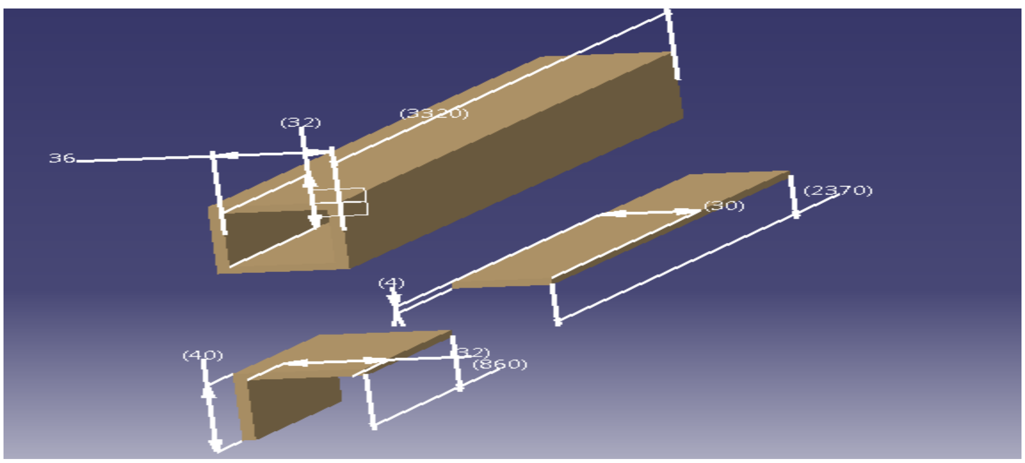

Figure 3. 4. Isometric view of the frame.

- Internal and external surface areas of the hallow pipe was computed using the following equation (Math.com,2012);

  $A_{sp}=A_o+A_i$……………………………………………………………..3.4

- Material Volume of the frame was calculated as follows,(ITSI-SU,2011)**;**

  $V_{sp}=V_o - V_i$ ………………………………………………………………….3.5

- Material Mass of the hallow pipe was also calculated using the equation,(ITSI-SU,2011);
- Given density of iron. 7870kg/m^3.

  $M_{sp} = d \times V_{sp}$…………………………………………………………….3.6

Where: A_o=outer cross sectional area of squire pipe

A_i= cross sectional area of inner part

V_{sp}= volume of squire pipe

M_{sp}=mass of squire pipe

P_{sp}= density of squire pipe

V_o = volume of outer pipe

V_i= volume of inner pipe

d = density of the iron pipe

- Area of circular pipe was calculated as:

$A_{cp} = \pi(R^2 - r^2)$ ……………………………………………………………………3.7

$V_{cp} = \pi(R^2 - r^2) \times L$……..3.8

- Mass of the circular pipe was calculated:
- Since the circular pipe is aluminum its density is =2710kg/m^3

$M_{cp} = V_{cp} \times p$..3.9

Where: A_{cp} is area of circular pipe

V_{cp} = volume circular pipe

V_{cp} = volume of circular pipe

M_{cp} = mass of circular pipe

R= outer radius

r=inner radius

- Area of two sheet metal was calculated as following:

$A_s = 2\times((W_s \times L_s) - \pi r^2))$……………...……………….…………….………..…...3.10

- Volume of sheet metal was computed using the equation of:

$V_s = A_s \times L_s \times t$..3.11

- Mass of the sheet metal was calculated:

$Ms = Vs \times p_s$ 3.12

Where: As= area of sheet metal

V_s= volume sheet metal

M_s= mass of sheet metal

W_s = width of sheet metal

P_s= density of sheet metal

L_s = length of sheet metal

t = thickness of sheet meta

- Total weight of the angle iron is half of squire pipe

$$A_a = \frac{L \times W}{2} \qquad 3.13$$

- Volume of the angle iron

$$V_a = \frac{vo - vi}{2} = \frac{(Lo \times Wo \times to) - (Li \times Wi \times ti)}{2} \qquad 3.14$$

- Mass of the angle iron

$$Ma = v_a \times d = \qquad 3.15$$

Where: A_a is area of angle iron

V_a= volume of angle iron

M_a = mass of angle iron

V_{ao}= volume of angle iron

Lo=length of outer pipe

W*o*=width of outer pipe

d = density of squire pipe

t_o=thickness of outer pipe

Li = length of inner pipe

Wi =width of inner pipe

t_i = thickness of inner pipe

L=Length of squire pipe

- Area of flat iron

$$A_f = w_f \times L_f \qquad 3.16$$

- Volume of flat iron

$$V_f = L_f \times W_f \times t_f \qquad 3.17$$

- Density of iron is 7870 kg/m^3
- Mass of flat iron

$$M_f = V_f \times d \qquad 3.18$$

Where: A_f is area of flat iron

w_f =width of flat iron

L_f=length of flat iron

V_f =volume of flat iron

t_f= thickness of flat iron

M_f=Mass of flat iron

d= density of iron

3.5.2.2. Separator sieve

The sieve was made from flat iron and round bar. The 15150 mm length of 10 mm diameter round bar was cut in different size, 23 of them are 600 mm size to welded to flat iron in both sides and 15 are 90 mm length of fingers. The area, volume and mass for flat iron and round bar of the separator was calculated as:

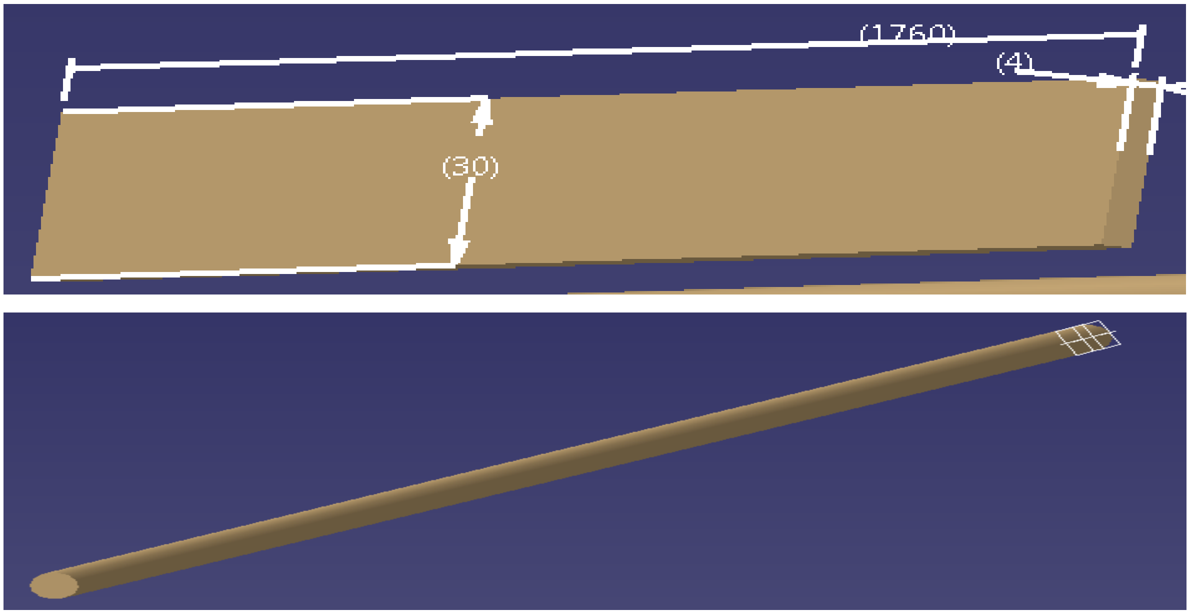

Figure 3. 5. Isometric view of separator

- Area of the sieve, flat iron and round bar can be calculated as follows

$$A_{fi} = L_{fi} \times w_{fi} \quad (3.19)$$

- Volume of flat iron was calculated by the equation of,

$$V_{fi} = A_{fi} \times w_{fi} \quad (3.20)$$

- Mass of flat iron was computed as follows:

$$M_{fi} = V_{fi} \times d \quad (3.21)$$

Area of round bar was calculated as

$$A_{rb} = 23 \times 2\pi r(r + h) \quad (3.22)$$

- Volume of round bar was calculated as:

$$V_{rb} = \pi r^2 \times h \quad (3.23)$$

- Mass of round bar was calculated as:

$$M_{rb} = V_{rb} \times d \quad (3.24)$$

- Weight of round bar was calculated as:

$$W_{rb} = M_{r.} \times g \quad (3.25)$$

Where: A_{fi}=area of flat iron

V_{fi}= volume of flat iron

L_{fi} = length of flat iron

M_{fi} = mass of flat iron

w_{fi}= width of flat iron

$W_{fi=}$ weight of flat iron

A_{rb}=Area of round bar

V_{rb}=volume of round bar

M_{rb} = mass of round bar

W_{rb}= weight of round bar

d = density of iron

h= height of round bar

r=radius of round bar

3.5.2.3. Weight of longitudinal flat iron

Four flat irons was used to link the sieve with the reciprocating ruler and the frame at the rear part

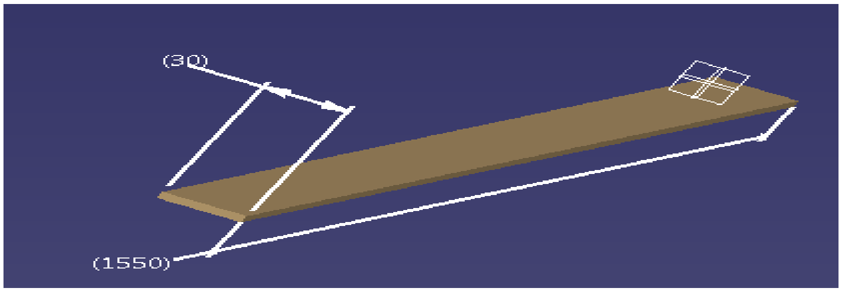

Figure 3. 6. Isometric view of rear part supporting of the sieve

This have two-rear part supporting of the sieve as you can see in the above, so can be calculated as:

- Area of supporting rear part of separator was calculated as:

A_{rf} =w × L……………………………………………………………………3.26

- Volume of supporting rear part of separator was calculated as:

$V_{rf} = A_{rf} \times t$…………………………….……………………….….....3. 27

- Mass of supporting rear part of separator was calculated as:

$M_{rf} = V_{rf} \times p_{rf}$……………………………………..…………………...3. 28

Where: A_{rf} is area of the flat iron at rear and front of the separator

V_{rf} = volume of flat iron at rear and front of the separator

M_{rf}= mass of flat iron at rear and front of the separator

w_{rf} = width of flat iron at rear and front of the separator

L_{rf}= length of flat iron at rear and front of the separator

p_{rf} = density of flat iron at rear and front of the separator

3.5.2.4. Weight of reciprocating ruler

Reciprocating ruler made from angle iron

- Area of Reciprocating ruler was calculated as:

$A_r = w_r \times L_r$………………………………………………………….…3.29

- Volume of Reciprocating ruler was calculated as:

$$V_r = w_r \times L_r \times t_t \text{ .... } 3.30$$

- Mass of Reciprocating ruler was calculated as:

$$M_r = V_r \times p \text{ .... } 3.31$$

Where: A_r is area of reciprocating ruler

w_r =width of reciprocating ruler

L_r = length of reciprocating ruler

V_r= volume of reciprocating ruler

T_r = thickness of reciprocating ruler

M_r= mass of reciprocating ruler

P= density of iron

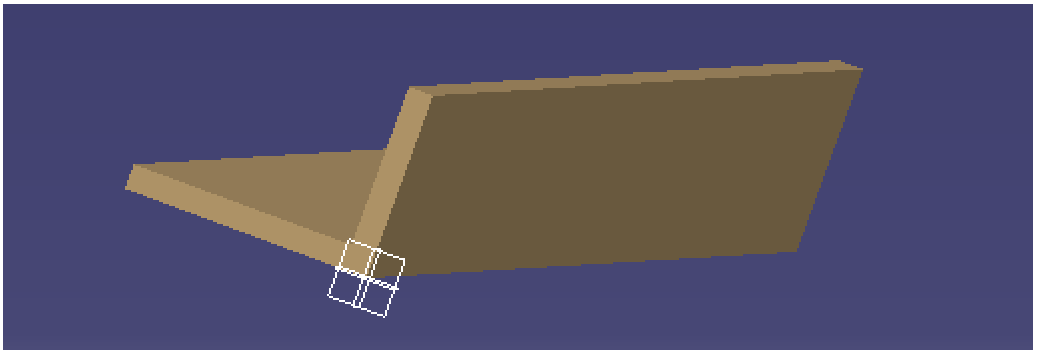

Figure 3. 7. Isometric view of reciprocating ruler

3.5.2.5. Weight of metal wheel and supporting wheel

Metal wheel of the digger was made of 6mm x 80mm sheet metal and has four spokes round bar so the weight of the wheel was calculated as:

- Area of the wheel was calculated as:

$$A_w = L_w \times W_w \text{ .... } 3.32$$

- Volume of the wheel was calculated as:

$$V_w = L_w \times W_w \times t_w \text{ .... } 3.33$$

- Mass of the wheel was calculated as

$$M_w = V_w \times d \text{ .... } 3.34$$

- Area of the spokes

$$A_{pk} = 2\pi r(r+h) \text{ .... } 3.35$$

- Volume of the spokes

$V_{pk}=\pi r2 \times h$……………………………………………………………………..…..….3.36

- Mass of the spokes

$M_{pk}= V_{pk} \times d$ ……………………………..……………………………..…………….....3.37

Where: A_w is area of wheel

L_w = Length of wheel

W_w = Width of wheel

V_w=Volume of wheel

M_w = Mass of wheel

t_w= thickness of wheel

r= radius of spokes

d= Density of iron

A_{pk}= Area of spokes

V_{pk} =Volume of spokes

M_{pk}=Mass of spokes

h=height of spokes

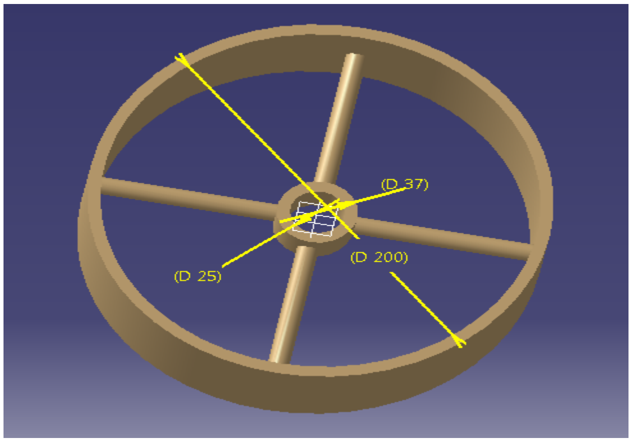

Figure 3. 8. Isometric view of ground wheel

3.5.2.6. Weight of pulley

Pulley was made of aluminum size of 160mm diameter and 80mm long. This material had grooved in two parts size of 22mm top width and 10mm bottom 3.6mm height, total mass of the pulley without the grooved part was computed:

$A_p=2 \times \pi \times (ro(r_o + h) - r_i (r_i+ h))$……………………………………..…………...……3.38

$V_p = \pi \times h \times (r_o^2 - r_i^2)$ …………………………………………..…………………3.39

$M_p= V_p \times d_a$………………………………………………………………………..…3.40

Where: A_p is Area of the pulley

V_p =Volume of the pulley

M_p= Mass of the pulley

d_a =density of aluminum

h= height of pulley

r_o = radius of outer pulley

r_i= radius of inner pulley

h = height of pulley

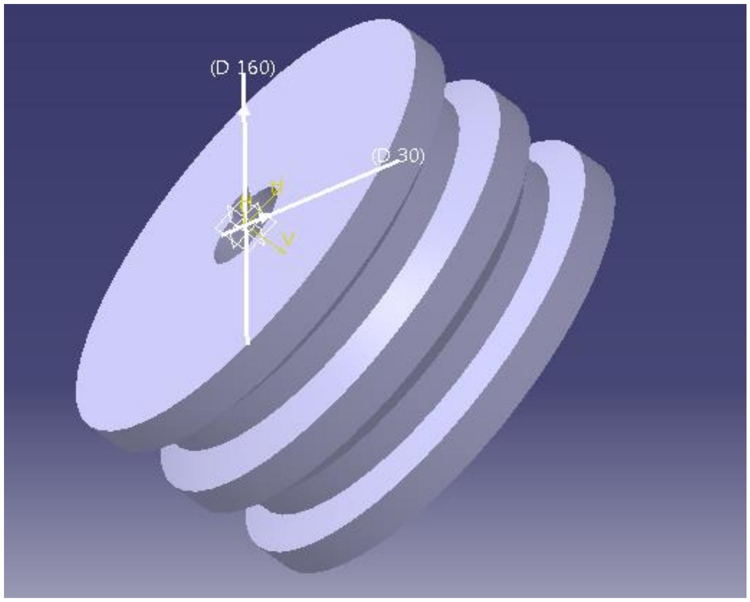

Figure 3. 9. Isometric pulley

Weight of the grooved pulley was calculated

- Area of the groove was calculated as:

  $A_g = 2 \times (l \times w)$……………………………………………………………………... 3.41

- Volume of the groove was computed as:

  $V_g = 2 \times (L_g \times W_g \times h_g)$…………………………………………………...…… 3.42

- Mass of the groove was calculated as:

  $M_g = V_g \times d_a$……………………….…….....……………………………………………….…3.43

  $M_t = M_p - Mg$…………………………………………………………………….....3.44

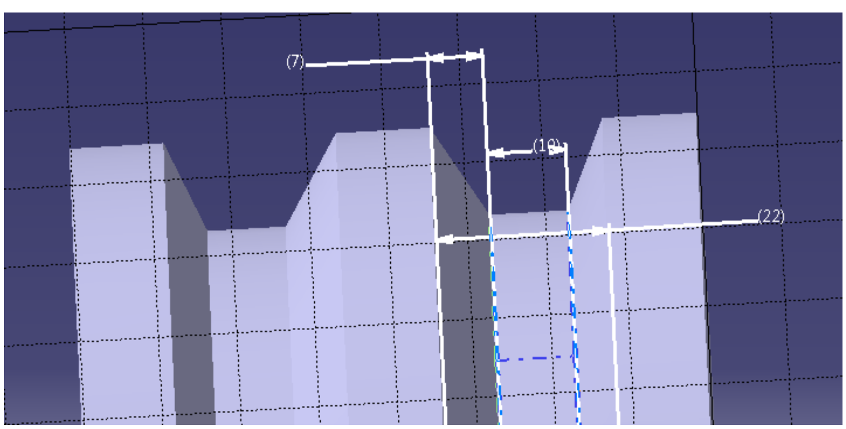

Figure 3. 10. Isometric view of pulley groove

Where: A_g is Area of the groove

V_g =Volume of the groove

L_g= length grooved of pulley

W_g = width of grooved of pulley

h_g= height of grooved of pulley

M_g =Mass of the groove

3.5.2.7. Weight of blade

The blade was made of 1470mmx100mm x3mm sheet metal as shown in the .Fig 3.11.

- Area of the blade was calculated as:

$A_{b1}=L_{b1} \times h_{b1}$……………………………………………………..……..……..…….3.45

$A_{b2}= L_{b2}\times h_{b2}$………………………………………………………..……..…..…….3.46

$V_{b1}= L_1 \times W_1 \times t_1$……….……………………….……………….……….……...3.47

$V_{b2} =0.5 \times L_2 \times W_2 \times t_2$…………...……………………………….……………...3.48

- Mass of the blade calculated as:

$M_b= V_b \times d$…………………………..………………………..…….……….3.49

Where: $A_{b=}$ area of blade

V_b= volume of blade

M_b= mass of blade

W_b = weight of blade

L_b=length of blade

h_b= height of blade

t_b = thickness of blade

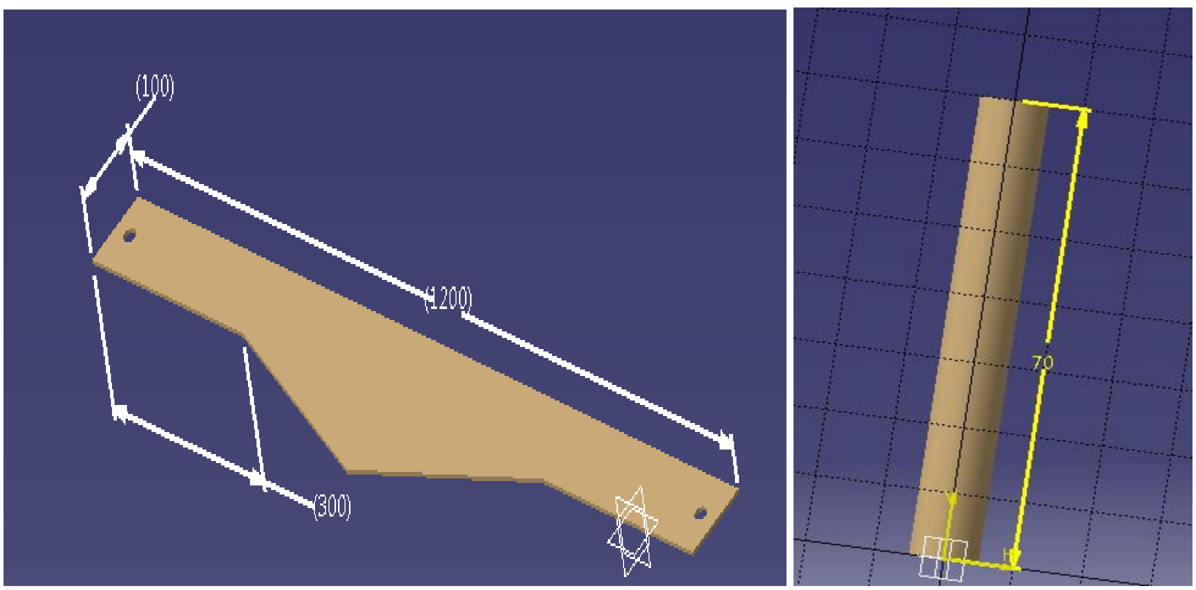

Figure 3. 11. Isometric view of blade and it's finger

3.5.2.8. Weight of shaft

Over all weight of the Shaft was calculated:

- Area of shaft was calculated as:

$$As = \pi r^2 \qquad (3.50)$$

- Volume of shaft was calculated as:

$$Vs = \pi r^2 \times Ls \qquad (3.51)$$

- Mass of shaft was calculated as:

$$Ms = Vs \times d \qquad (3.52)$$

Where: As is area of shaft

Vs= volume of shaft

Ls= length of shaft

Ms = mass of shaft

3.5.2.9. Weight of stand for the two squire pipes and round bars

- Area of the two stand

$$A_{st} = 2 \times (W \times L) \qquad (3.53)$$

- volume of the two stand

$$Vs_t = (W \times L \times T) \qquad (3.54)$$

- Mass of the two stand

$$M_{st} = V_s \times d \qquad (3.55)$$

Weight of the two pin welded to stand

- Area of the two round bars

$$A_{rw} = 2 \times \pi r^2 \qquad (3.56)$$

- Volume of the two round bars

$$V_{rw} = \pi r^2 \times h \qquad (3.57)$$

- mass of the two round bars

$$M_{rw} = V_{rw} \times d \qquad (3.58)$$

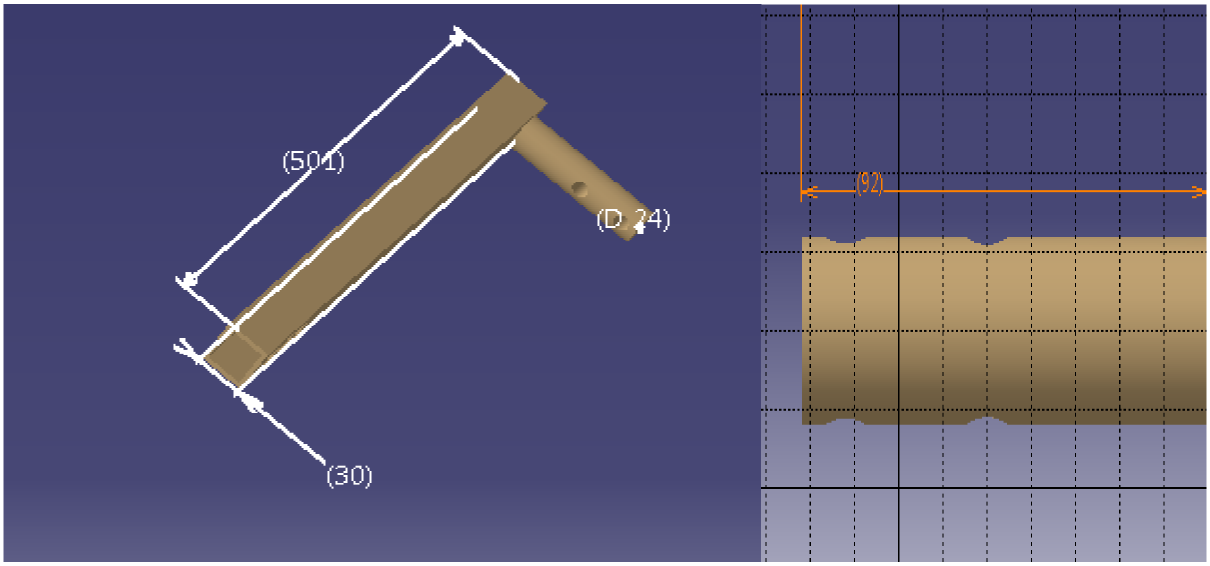

Figure 3. 12. Iso-metric view of stand

Where: A_{st} is area of the stand

Vs_{t} =volume of the two stand

M_{st} =Mass of the two stand

A_{rw} =Area of the two round bars

V_{rw}=Volume of the two round bars

M_{rw}=mass of the two round bars

3.5.3. Blade design

The sheet metal of 3cm thickness and 626cm length was used, later this was bended both sides in 90^0 and forming a v-shaped 58 cm length blade as it can be shown in the figure 3.13. Blade is designed using CATIA v5 software every dimension is measured according to the size of the blade 60cm ×10cm ×30cm, which is length, width and height. The blade was designed based on the row width of the potato tuber. As per the data collected from the field the ridge was 60 cm wide and the row spacing between the ridge is 30cm. (Kurtz et al.1984).The total draft of the digger was ,(Sharma, 2010).

$$D = ko \times n \times w \times d \qquad 3.59$$

Where: D is draft force, kg

K_O =Specific soil resistance 0.12kg/cm2, when the condition is light

W=Width of blade, cm

d=Depth of blade, cm

N=number blade

Table 3. 3 Specific soil resistance at depth of 12cm

S.no	Soil type	specific soil resistance, kg/cm3
1	Light	0.12
2	Medium	0.15
3	Heavy	0.20
4	Very Heavy	0.25

Source: (Duby, 2003)

Ismail et al. (2015) Stated that the blade was calculated its area, depth and the capacity that the blade can dig and carry the soil as follows.

$A_d = L_d \times w_d$ ……………………………………………………………………………..3.60

$V_{soil} = A_d \times H$……………………………………………………………………….3.61

Weight of the soil on the digger

$W_{soil} = m_{soil} \times g$……………………………………………………………………….....3.62

$m_{soil} = \rho_{soil} \times V_{soil}$………………………………………………………………….3.63

Therefore, total weight applied on the 2WT Potato digger was summation of Weight of components of the digger and weight of the soil calculated as:

$W_T = Ws + Wc$……………………………………………………………………………3.64

Thus, moment affected on the blade was derived by half of Length multiplied by weight of the soil.

$M = Wsoil \times L/2$……………………………………………………………………………...3.65

To determine the thickness of digger blade “t” Bending moment on digger blade

$M = \frac{\sigma y \times L_d \times t2}{6}$………………………………………………………………………..3.66

Where: H is height of the digger

L_d = length of the digger

A_d = area of the digger

V_{soil} = volume of the soil on digger

m_{soil} = mass of the soil on digger

Wsoil=weight of the soil on digger

σy = yield stress

M=bending moment of the blade

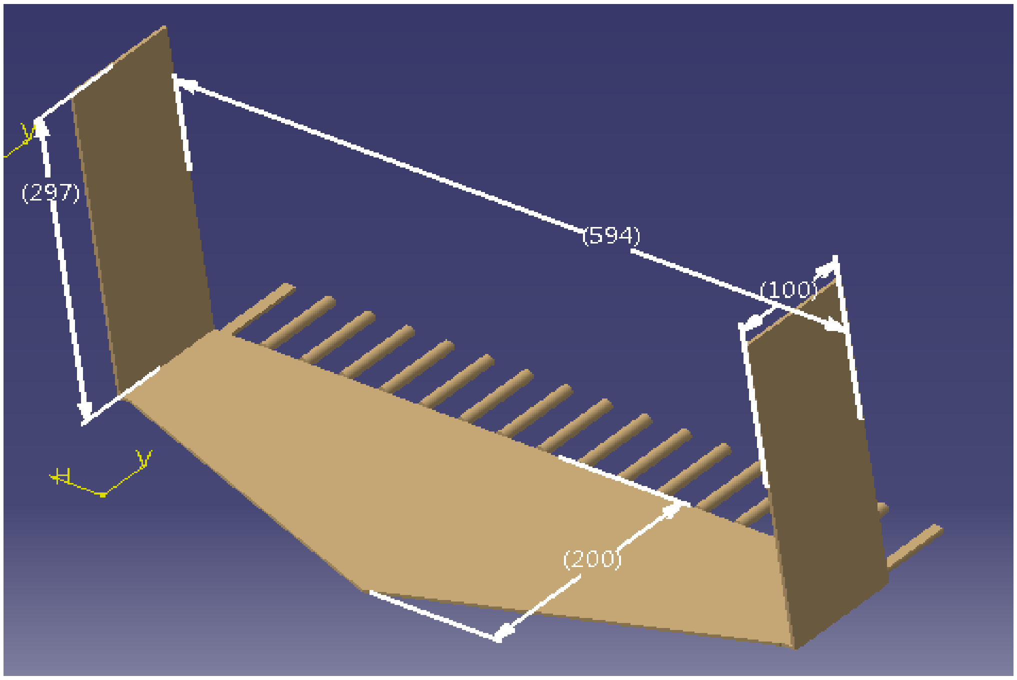

Figure 3. 13. Cutting blade

3.5.4. Rod type Separators design:

Separator Consist of straight steel bars linked together with gaps to enable soil and debris to be shake with adjustable agitation. Operator must ensure that agitation is minimal to avoid tuber damage. The agitation process was done by placing an elliptical type of flat cam rounding freely in the camshaft and this cam is connected to arm. Because of the rounding of the pulley the rods moves linearly with constant speed (v). The separator takes its movement from the power source; motion transmission between them was done using a circular pulleys and V-belts. Quality of separator depends on the following parameters: Width of separator, length of separator, angle of inclination, speed of separator and degree of vibration. Width of separator depends on crop rows and width of farrow. Length of separator depends on separation performance and tubers losses. Increasing the length increases the performance. Diameter of the tuber determine the gap between rods. The number of rods required in the digger was calculated as:

$L = n \times S_r + n \times d_r$……………………………………………………….……...……..3.67

Where: L=length of the rod

n= number of rods

dr= diameter of rod

Sr=spacing between the rods

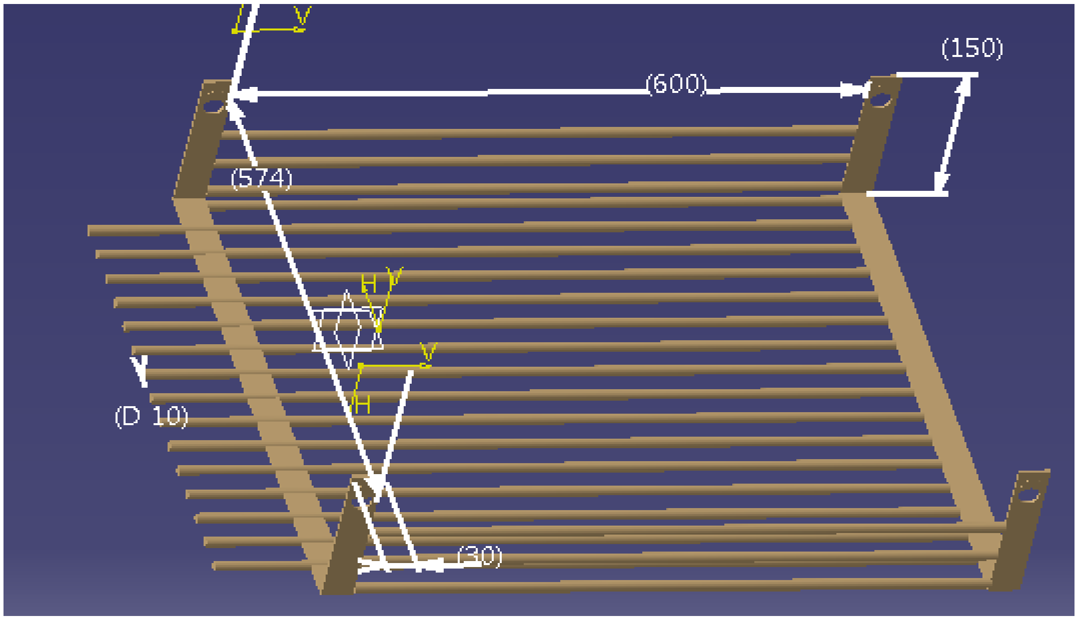

Figure 3. 14. Separator

3.5.5. Frame

The frame is the upper part of the digger, to which all components and accessories of the digger are attached. It was made up of squire pipe mild steel of dimensions 0.87 m × 0.50 m × 0.065 m respectively, as length × breadth height. The frame attaches to the blade, separator (shaker) and the pulley of the digger.

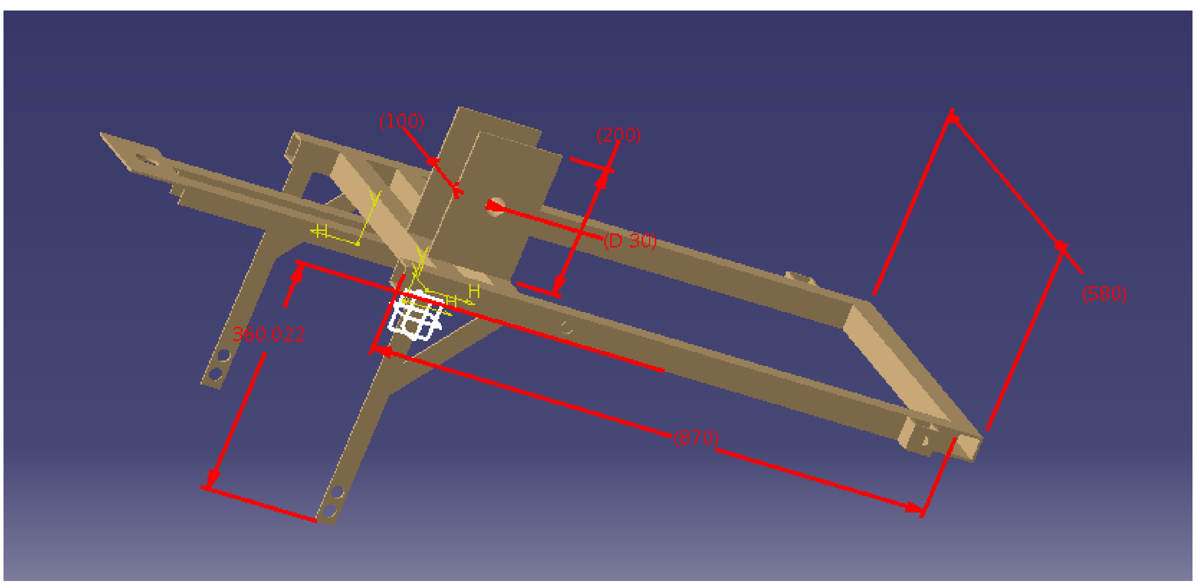

Figure 3. 15. Frame of the digger

3.5.6. Cam drive and arm

A cam mechanism usually consists of two moving elements, the cam and the follower (arm), mounted on a reciprocating ruler. The cam drives connected to the output shafts of the camshaft together with the arm produced the oscillatory motion. The rotary motion of the camshaft was converted to the oscillatory motion of the arm by providing an eccentricity of 30mm. The arm transferred this motion to the oscillating fingers connected to them. The possible applications of cams are unlimited, and their shapes occur in great variety. Some of the most common forms will be considered in this equation. During full rotation of the camshaft, the plate cam rotates to dwell for half of the rotation, rises for a quarter and fall for the next quarter to complete the motion. The period of dwell of the cam is to allow the finger sieve for the back and fro motion. The resulting motion of the follower is transmitted to the finger sieve via reciprocating ruler (Raji *et al.*, 2010). Figure 3.16 shows a schematic view of the system.

$s = r + a \cos\theta$..3.68

$s=0.01m+0.0.03\ m \cos 0^0= 0.04m$

$s=0.01m+0.03\ m \cos 90^0= 0.01m$

$s=0.01m+0.03m \cos 180^0= -0.0185m$

$s=0.01m+0.03m \cos 270^0= -0.0036m$

As you can see from the above results, the follower gets its higher position when the cam rotation angle is 0^0, as well as gets the lower position at 180^0.

Where: s = Displacement of follower at a cam rotation angle θ

r = True radius of the cam, mm

a = Offset distance between the cam true center and the center about the cam rotating, mm.

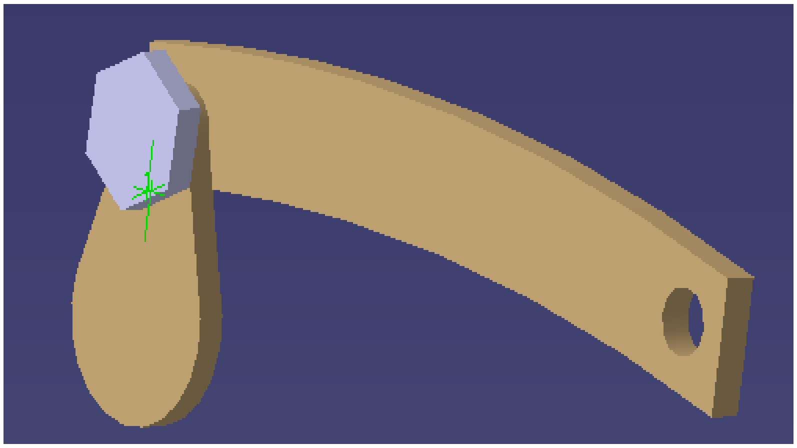

Figure 3. 16. Cam profile and arm

3.5.7. Shaft design (selection)

A shaft is a rotating component of machine, used to transmit power from one source of power to another. In two-wheel tractor drawn one row Potato digger, it was designed 40cm long and 25cm diameter of shaft. In order to transfer the power from the engine of the two-wheel tractor to the implement of the potato digger, pulleys and v-belt are attached to it.

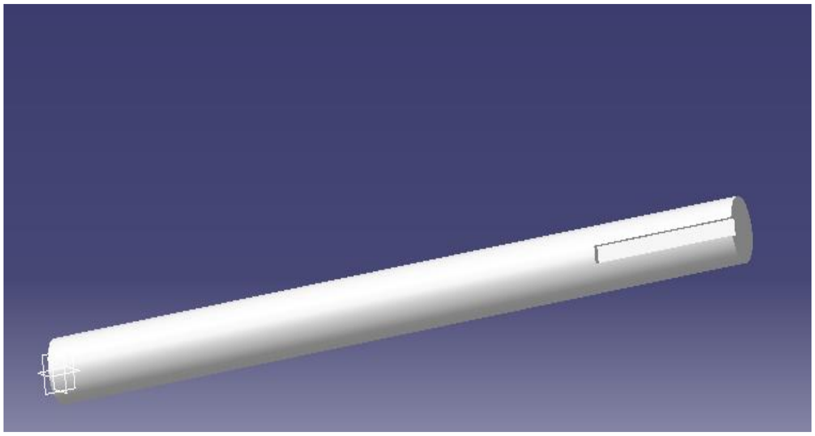

Figure 3. 17. Shaft isometric view

Theodre (1985) determined the failure of the shaft was likely to be in shear stress and the design considered this fact. Considering this shear stress, the diameter of the shaft is given by:

$$d^3=\frac{16}{ss x \pi}\sqrt{(Kb.Mb)2\ +\ (Kt.Mt)2} \quad \ldots\ldots 3.69$$

Khurmi et al. (2005) recommended to use the following values in the designing of diameter of the shaft when load was suddenly applied with minor shock.

Where: d = diameter of the shaft; mm

Mt= torsional moment; 40Nm

Mb= bending moment; Nm

Kb= combined shock and fatigue factor applied to bending moment; 1.2 to 2.0

Kt= combined shock and fatigue factor applied to torsional moment; 1.0 to 1.5

Ss= allowable stress; $55MN/m^2$

Torsional moment (Mt) on the shaft was 40 Nm, then the Shaft subjected to bending moment only then the maximum bending moment on the shaft was determined from the bending moment diagram as equation (3.73) (Richard *et al.*, 2011).

$M_b = \sqrt{(MV)^2+(Mh)^2}$ ………………………………………………………………………..3.70

Where: M b = Maximum bending moment, Nm

Mv = Vertical bending momentum see figure.3.21 bending moment diagram

Mh = Horizontal bending momentum see figure.3.19 bending moment diagram

In this case, it can be taken 30mm diameter and 400mm standard shaft

a) Horizontal shear force and bending moment distribution

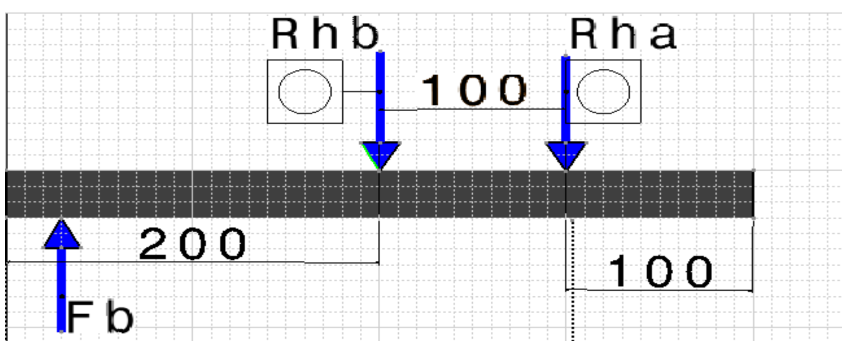

Figure 3. 18. Horizontal force distribution on the shaft

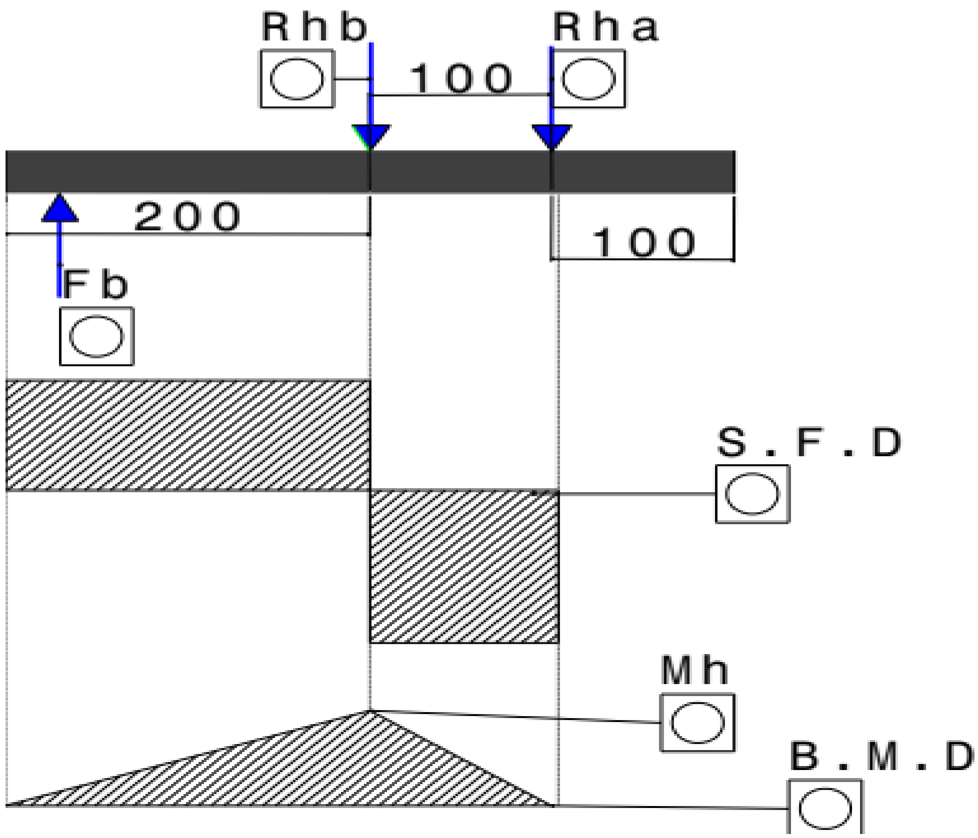

Figure 3. 19 Horizontal shear force and bending moment diagram

By applying equilibrium equation, the following was solved.

$F_b = R_{hb} + R_{ha}$……………………………………………………………………………..3.71

Where: F_b is force of the belt

R_{ha}= supporting force at point "a"

R_{hb}= supporting force at point "b"

M_h=Maximum bending moment

$\sum Ma = 0$…………………………………………………………………………………3.72

R_{hb} and R_{ha} was calculated from the above moment equation.

b) Vertical shear force and bending moment distribution

The vertical load diagram on the driven pulley shaft was as shown below .Total weight of driven pulley which lay on the shaft was 39.73 N. In the equilibrium condition:

$W_p = Fv_a + Fv_b$……………………………………………………………………….…..…3.73

Where: W_p is weight of pulley

Fv_a and Fv_b are vertical supporting force

$\sum Ma = 0$………………………………………………………………………………….3.74

Fv_a and Fv_b was calculated from the moment at point a.

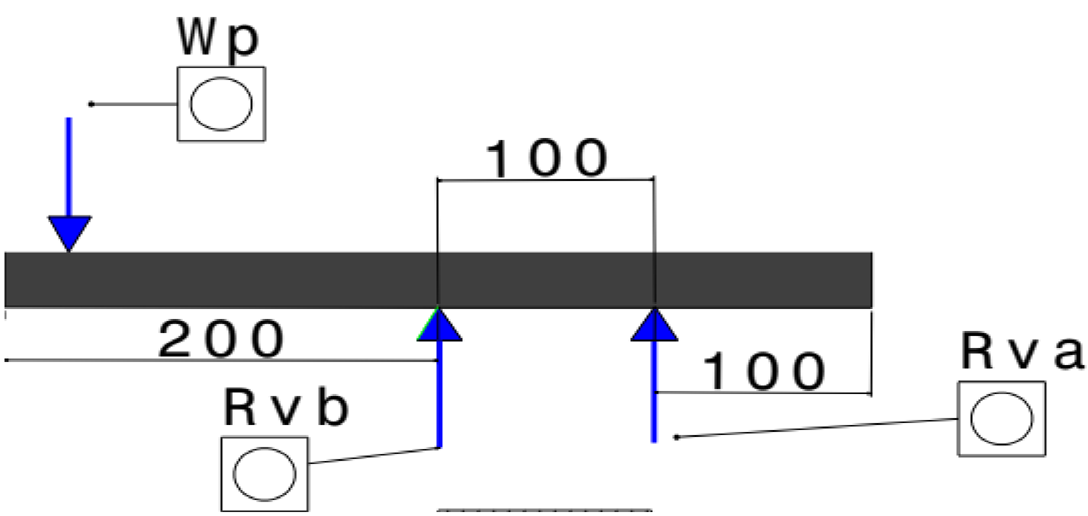

Figure 3. 20. Vertical force distribution on the shaft

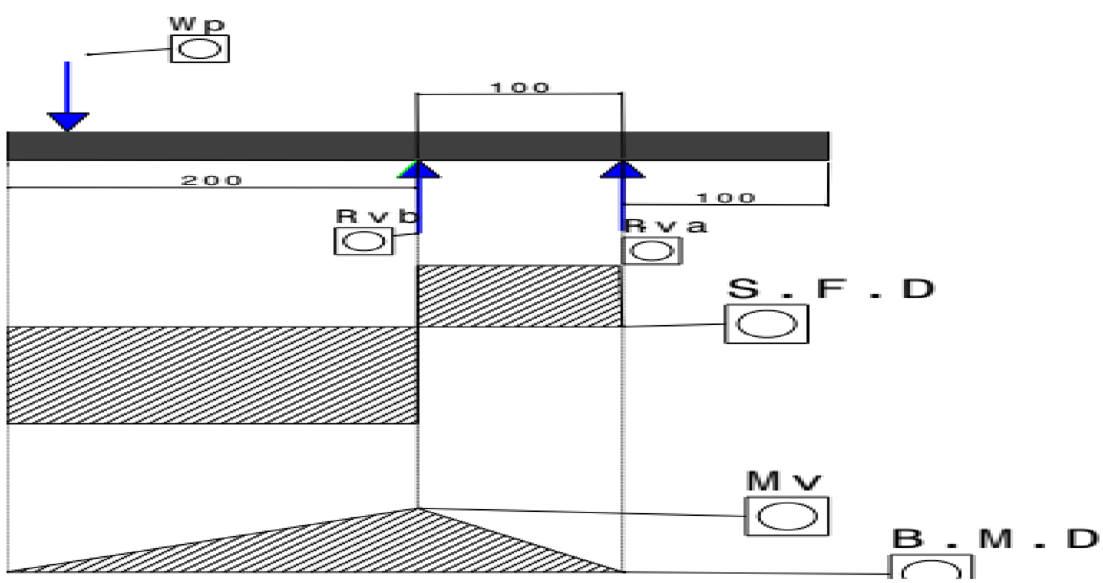

Figure 3. 21. Vertical shear force and bending moment diagram

3.5.8. Pulley design

The designed Pulley transmits power to the oscillator from the power tiller flywheel through B section v-belt. The selected driving pulley diameter was 16cm and the driven wheel diameter was 34cm at speed of driving pulley 1600rpm and speed of driven pulley 800rpm.

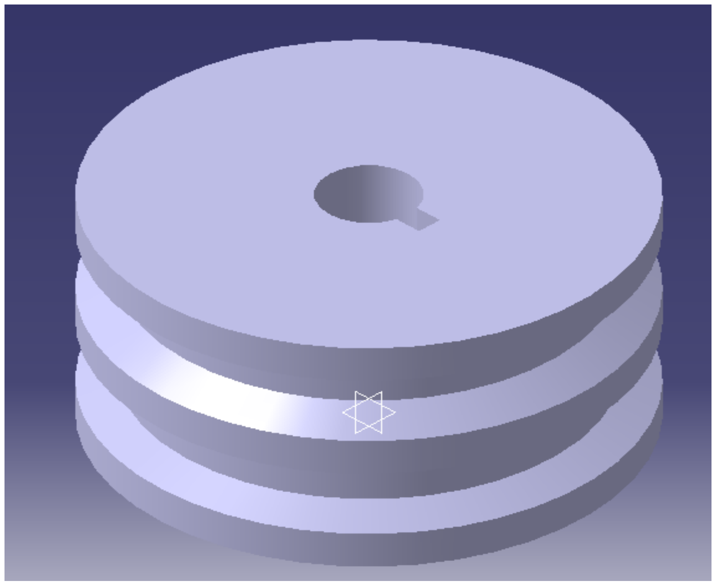

Figure 3. 22. Pulley

3.5.9. Belt selection

V-belt was used in the designing of two-wheel tractor drawn one row potato digger. A V-belt is the most widely used type of belt, particularly in automotive and industrial machines. It rotates over the inside the groove aluminum pulley. V-belts are made of rubber covered with rubber or polymer impregnated fabric and reinforced with nylon or polyester. The wedging action of a v-belt in a pulley groove results in a drive which is more compact than a flat belt drive, but short center V-belt drives are not conducive to shock absorption. The V shape causes the belt to wedge tightly into the pulley, increasing friction and allowing higher operating torque. A V-belt or rope meshing in a V-shaped groove of the pulley increases greatly the frictional resistance to slipping, for a given maximum belt tension, as compared to flat belt. The cross-section of a V-belt is trapezoidal as shown in Fig 3.23.The thickness b, ranges from 8 to 19 mm and the width ranges from 12.5 to 38 mm. The belt section angle may be around 40°. Manufacturers have standardized the cross-sectional dimensions of V belts, with each section designated by a letter of the alphabet. Dimensions, minimum sheave diameters, and the horsepower range for each of the lettered sections were listed. Standard circumferences are listed in (Table 3.5). For example, B75 is a B-section belt having an inside circumference of 75 in. For any given belt section, the pitch length is obtained by adding a quantity to the inside circumference (Shigley's *et al.*, 2011).

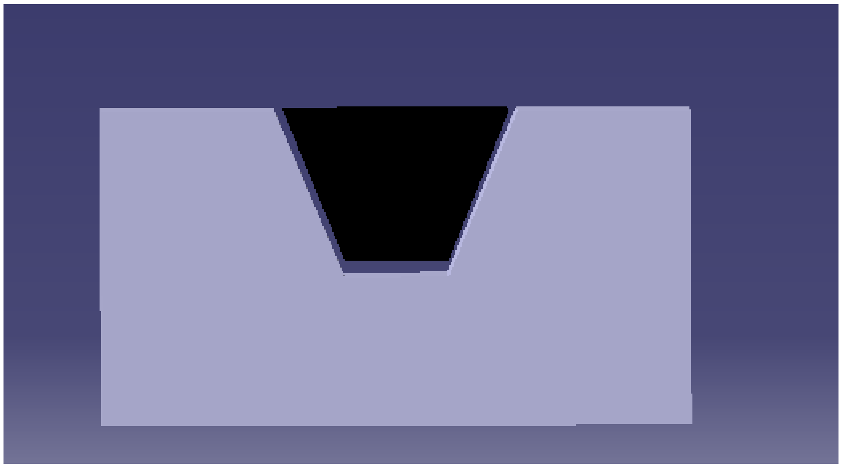

Figure 3. 23. Belt design

Table 3. 4 Belt size of the v- belt section and horsepower range

Belt section	Width ,a (m)	Thickness, b (m)	Mini.sh.dia. (m)	HP two belts
A	0.013	0.009	0.0762	0.25-10
B	0.0167	0.01	0.1371	1-25
C	0.022	0.013	0.2286	15-100

Source: (Shigley's *et al.*, 2011)

Table 3. 5. Inside circumference of standard v-belt

Section	Circumference(m)
A	26, 31, 33, 35, 38, 42, 46, 48, 51, 53, 55, 57, 60, 62, 64, 66,
B	35, 38, 42, 46, 48, 51, 53, 55, 57, 60, 62, 64, 65, 66, 68, 71, 75, 78,79, 81, 83, 85, 90, 93, 97, 100,
C	51, 60, 68, 75, 81, 85, 90, 96, 105, 112, 120, 128, 136, 144,

Source: (Shigley's *et al.*, 2011)

Table 3. 6. Horse power rating of v-belt

Belt section	Sheave pitch diameter, in	Belt speed(fit/min)				
		1000	2000	3000	4000	5000
A	2.6	0.47	0.62	0.53	0.15	
	3.0	0.66	1.01	1.12	0.93	0.38
	3.4	0.81	1.31	1.57	1.53	1.12
B	4.2	1.07	1.58	1.68	1.26	0.22
	4.6	1.27	1.99	2.29	2.08	1.24
	5.0	1.44	2.33	2.80	2.76	2.10
	5.4	1.59	2.62	3.24	3.34	2.82

Source: (Shigley's *et al*., 2011)

To design the v-belt select the suitable belt length from the table in the B-section row which is near to the calculated formula below. (Shigley's *et al*., 2011).

$L = 2C + \pi \frac{(D+d)}{2} + \frac{(D-d)2}{4c}$ ……………………………………………………..…………3.75

Where: L = Length of belt

D= pitch diameter of small pulley: = 130mm

d = Pitch diameter of big pulley: =270 mm

C = Center distance between the pulleys: = 400mm, therefore the overall length of the belt was 144 m selected from the table 3.6.

V-belt had diversified use due to its distinct advantages that, it: absorb vibration and shock, intending to transmit only a minimum to the connected shaft. It is quiet, if properly maintained and can be designed to have a long trouble life. From the speed ratio of the digger shaft to engine shaft, the speed of the shaft was obtained by the following equation (3.76) (Khurmi. et al. 2005).

Nd = nD..3.76

Where: N= angular speed of engine shaft = 1600 rpm.

D = diameter of driven pulley

n= angular speed of the digger shaft,1050 rpm

d = diameter of the driving pulley

From the above equation the maximum value of the angular speed of the driven pulley was 1050 rpm and the speed of the belt was determined by equation (3.77) (Khurmi et al., 2005).

$V=\frac{\pi dN}{60}$……………………………………….……………...……………….…………….…..…3.77

The tension force on the pulley must be calculated according to the following equations (3.77) (Khurmi et al., 2005).

$Tc = mv^2$ …………………………………………………………………………..………......3.78

Where: m = mass the pulley, kg

V = speed/velocity of the belt, m/s

The input power from the diesel engine was 9hp = 6714 watt and the maximum twisting moment developed on the shaft could determine from the input powered as equation (3.80) (Bashir et al., 2013).

$P_{in} = \frac{2\pi NT}{60}$……………………………...………………………………………………………3.79

Where: P_{in} = input power from engine was= 6714w or 9hp.

N = angular speed of the engine shaft, rpm

T = the twisting moment of the camshaft, Nm and the value from the above equation was calculated as:

The output power transmitted through the belt T_1 and T_2 of the digger was determined as the equation (3.81).

$P_d=\frac{2\pi nT}{60}$…………………………………………………...…………………………..……3.80

Where: P_d is output power required to dig the soil, w

T = twisting moment developed on the shaft, Nm

N_2 = angular speed of the shaft, rpm

The belt efficiency to transmit from the power source to offset rotating shaft was determined as the equation (3.82) (Shigley's *et al*., 2011).

Efficiency = $\frac{\text{output power}}{\text{input power}}$…………………………………………………………………….…3.81

F = (T1 – T2)……………………………………………………………….…………………3.82

F = (3Tc – T2)…………………………………………………………………….………3.83

Where: F = force required to drive the machine (N)

T_1 = Tension on the tight side of belt (N)

T_2 = Tension on the slack side of belt (N)

But the value of the driving force was determined from the output force as shown in the equation (3.85) (Bashir et al., 2013) below.

$P = Fv$ 3.84

Where: p = output (transmitted) power through belt T_1 andT_2, W

F = force required to drive, N

v = velocity of the belt, m/s

$T_1 = 3T_C$ 3.85

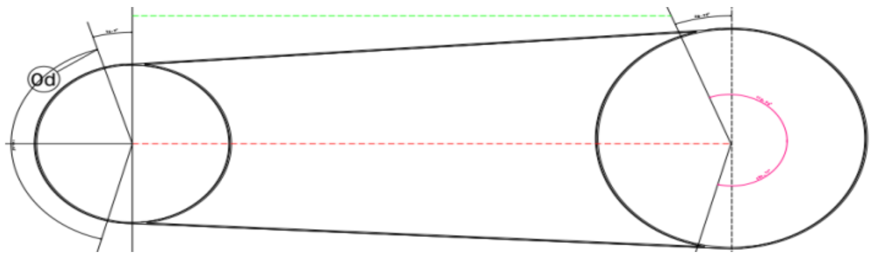

Figure 3. 24. Belt length and pulley diameter

3.5.10. Bearing selection

Bearing is a device that is used to fix a shaft in position in the pulley. Generally, it allows for constrained relative motion between two or more parts, typically rotation or rotational motion. In many cases involving bearing selection during the initial design of a machine, obtaining a satisfactory rating life is the prime consideration. The shaft size is usually decided first, based on allowable working stress and deflection. This establishes the bearing bores. Two 30mm diameter bearings are used in this work to connect the camshaft with pulley there are also two bearings 20 mm diameter each attached to the reciprocating ruler in two ends.

Bearings were selected according to the following criteria:

- The operating condition of machine (Capacity and direction of load).
- Mounting arrangement for the machine.
- Ease of mounting and dismounting of bearings in the machine.
- Space available in the machine.
- Cost of bearings.
- Readily availability of bearings.
- Desired life of bearing.
- Type of lubrication.

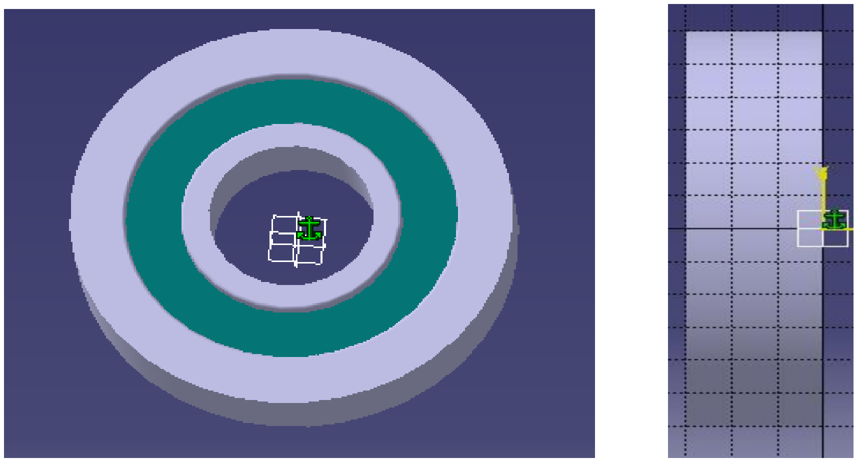

Figure 3. 25. Iso metric view of bearing

3.6. Fabrication of two wheel tractor drawn potato digger

The design of the two-wheel tractor driven potato digger was drawn using CATIA drawing software. The component parts of the prototype tubers includes: frame, blade, cleaning unit, pulleys and belts, bearings. The whole parts of the digger listed above were fabricated and assembled in the MAMRERC workshop. The cleaning unit is a sieve type having twenty one round bars length of 600mm, spaced at equal distance and arranged parallel. The materials that were used to manufacture the prototype encompasses hallow square section, angle iron, mild steel sheet metal, bolts and nuts, pulleys and belt, and bearings. The frame is 40x40x4mm squire pipe. The frame was made of 870mm length 600mm width. The blade was fabricated from M.S sheet metal. It had 600mm length, 200mm width and 300mm height size. The driven pulley was made of aluminum and had diameter of 180mm and 70mm width. This was connected with drive pulley from the two-wheel tractor. The v-belt was the power transmission system from the two-wheel tractor through the 30mm diameter camshaft to rotate the offset cam to change the motion to horizontal reciprocating motion. The wheel of the digger was 200mm in diameter. The ground wheel was made-up of 50mm × 4mm M.S flat metal having length 157 cm by bending in circular shape. It consists of four (4) spokes made from MS rod of 10 mm diameters And 450 mm long. These spokes were welded with the inner periphery of the rim and at the outer periphery of the hub. The hub was made of MS tube of 47mm length and with 70 mm outer and 30 mm inner diameters. Nut and bolt type locking arrangement was provided on wheel hub for its mounting on the short pin welded to vertical squire pipe.

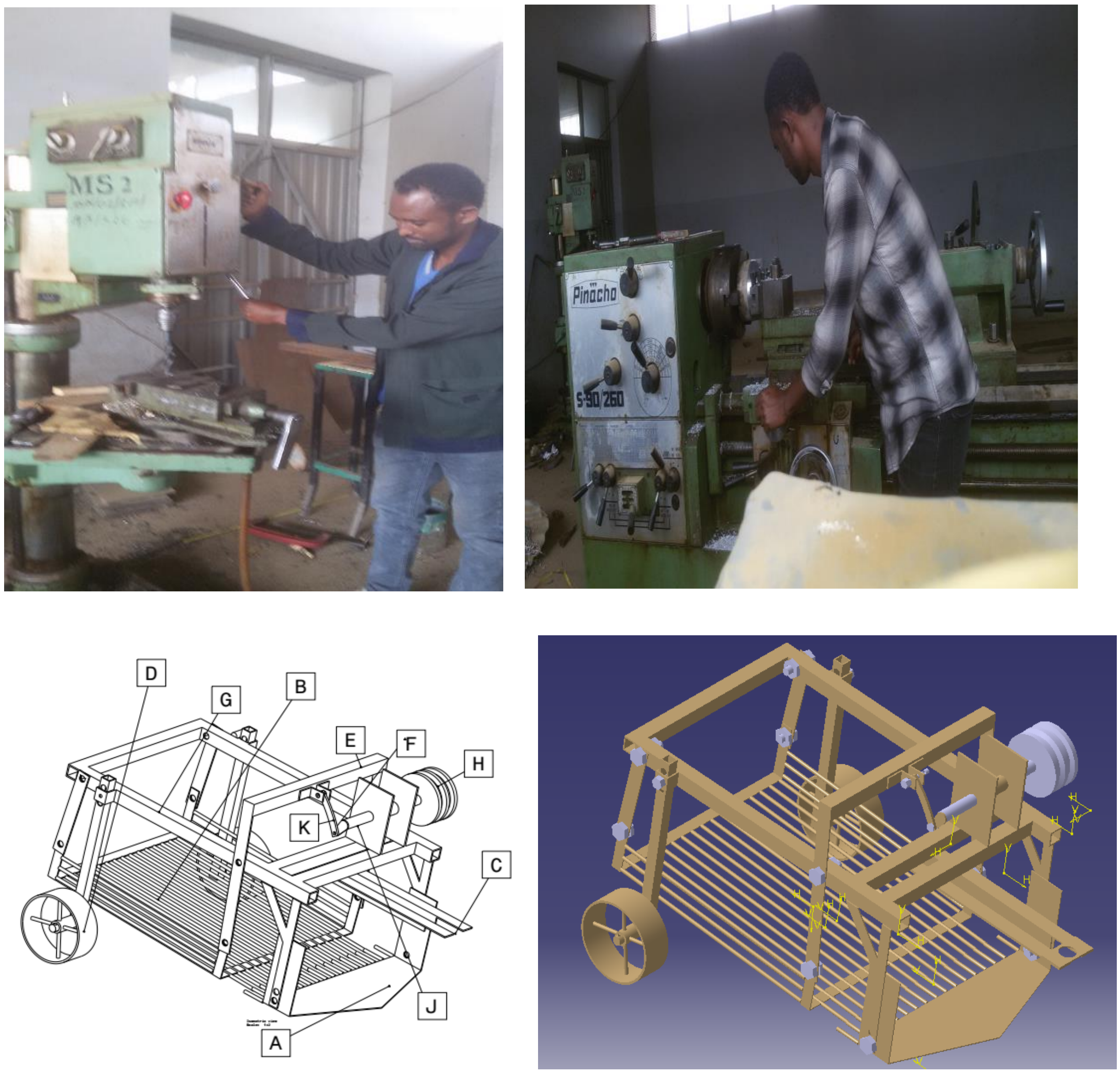

Figure 3. 26. Iso metric view of prototype digger

3.7. Performance evaluation of two wheel tracer drawn potato digger

The performance of the potato digger was tested in the laboratory as well as at Field. The prototype was tested in Mekelle agricultural mechanization and in the farmers field. The machine was evaluated in the laboratory for checking exposing the potato to the ground through horizontal motion. The performance of potato digger was evaluated in terms of travel speed, wheel slip, digging efficiency, digging capacity, damaged tuber (%), draft power, labor requirement and costs (fixed and variable).

3.7.1. Laboratory test

This test was consisted of the calibration of the digger and separating capacity of potato seed. The test was carried out at different setting, during the laboratory test the reciprocating motion was properly functioning to throw the potato to the rear part of the digger during two-wheel tractor was stationary.

The main objectives of laboratory test was to study the specifications, observe the performance of the components developed and to undertake such study that would assist in the modification and improvement of the developed machine. It was done to determine the uniform rotation of camshaft with separator, correct power transmission from engine camshaft through belt and pulley.

3.7.2. Field test

The potato digger was attached to the two-wheel tractor. Three different operating speeds were taken. The 1.4 km/h, 2 km/h and 2.5 km/h speed was selected for digging operation and effect of different operating speed on seed damage was observed. The best results' giving operating speed was chosen for digging. The digger was operated in a well prepared seed bed. During the test, seed damage, theoretical field capacity, effective field capacity, field efficiency and power requirement was found out.

Performance evaluation of power tiller is conducted in accordance with Indian Standard (IS):9935-2002 as amended from time to time. A power tiller is put into the following tests and evaluation: The organizational structure, responsibilities, procedures, processes and resources used to implement quality policy and objectives are collectively referred to as quality systems. To cope with the growing change of competitiveness, ISO 9000 series of standards has been formulated by ISO to provide for quality management systems. Indian has adopted ISO 9000 series of standards as IS/ISO 9000 series of standards. These standards provide not only guidance and criteria for formal control of products and services by the company but also give an assurance to the purchaser and the set of stated requirements.

3.7.3. Experimental design

The Experiments were conducted in the field with potato seed and the prototype was tested using three forward speeds of two-wheel tractor. The test was conducted at speed of 1.4km/h, 2km/h and 2.5km/h with three treatments and each treatment replicated three times. Randomized complete block design (RCBD) was used to reduce the experimental error due to unknown sources of variations such as soil heterogeneity to some extent. This design is the most commonly used in agricultural field experimentation. The experimental area is divided into regular blocks or replications and each replication contains a complete set of the treatments, which are allotted to the plots within each replication at random. The number of plots in each block (replication) should be equal to the number of treatments included in the experiment.

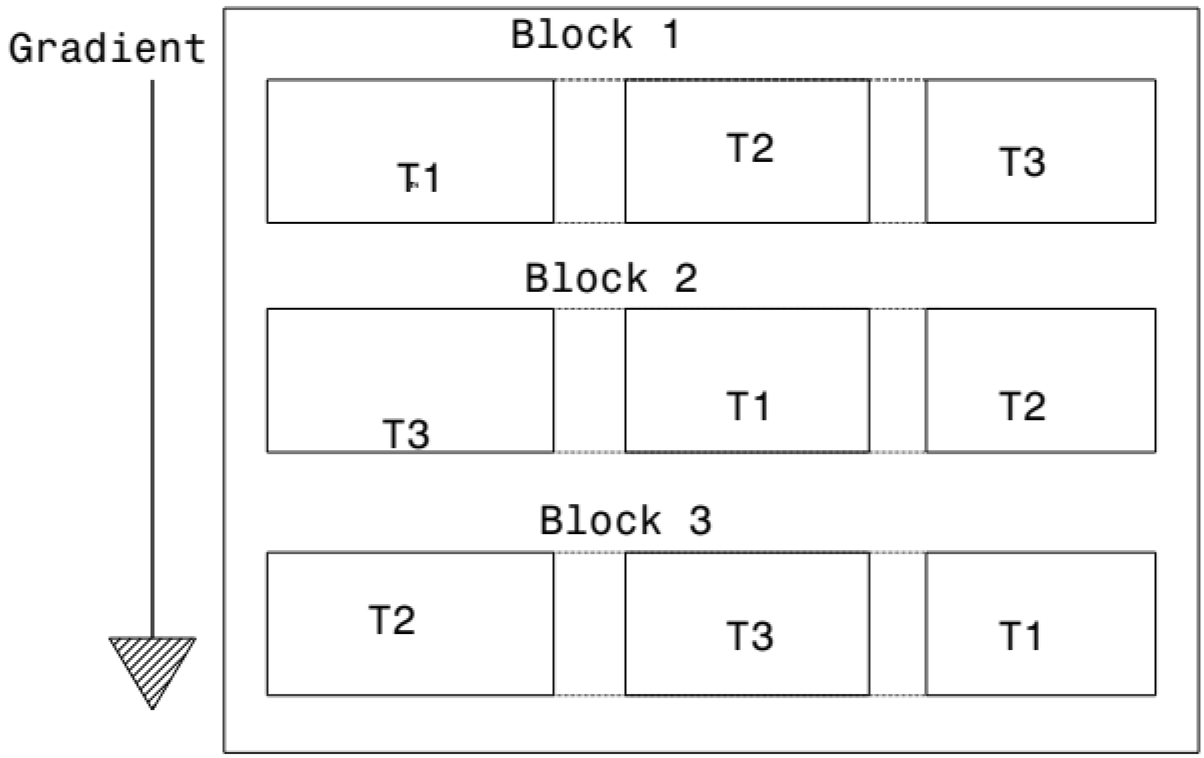

Figure 3. 27. Layout design

Where: T=treatments

1, 2, and 3 are indicating number

3.7.4. Harvested potato

The exposed potato to the ground was calculated to know how efficiently the oscillating conveyor was able to separate the potato from soil.

Attia (2020) was discussed the equation of Exposed potato as follows.

Exposed potato, % $=\frac{V}{H+V}x100$…………………………………………………….…3.86

Where: V is the total number of lifted potato or visible on the top surface of the soil.

H is the total number of uplifted potato by the root crop digger.

3.7.5. Undug Potato (loss)

The undug potato was calculated to know how much of the potato remained undug. It was defined as follows (Attia, 2020).

Undug potato (lose), %= $\frac{\mathrm{U}}{\mathrm{H+U+V}}\mathrm{x}100$……………………………………….……..…..3.87

Where: U is the total number of potato(lifted and un lifted.)

3.7.6. Soil parameters

3.7.6.1. Moisture content of soil

To determine the moisture content of the soil, five samples were taken from 12cm deep surface using metal auger manually pressing and twisting the tool and collect the sample to plastic bag. This was taken before test and weighing before oven dry (wet basis), The oven dry determines the moisture content of the soil after 24 hours. Lastly, the samples were weighed after oven dry (dry bases). Moisture content was calculated using the following formula ((Reddy et al., 2018).

Moisture content (%) = $\frac{\mathrm{Ww-Wd}}{\mathrm{Wd}}$x100 ……………………………………………………………..3.88

Where, W_w= Weight of wet soil sample, and

W_d= Weight of dry soil sample

3.7.6.2. Bulk density of soil

Bulk density of the soil was collected using 10cm diameter and 12cm length of metallic core sampler. The samples were weighed before and after oven dry. The ratio of dry basis to the volume of results bulk density of the soil and this calculated using the formula of (Rangapara, 2014).

Bulk density of soil (g /cc) $=\frac{\text{weight of dry soil sample(g)}}{\text{volume of core samoler(cc)}}$………………………………3.89

3.7.7. Performance parameter of potato digger

3.7.7.1. Operating speed

The operating speed of potato digger was carried out by recording the time required for traveling 40 m distance with the help of stopwatch to reach the longest distance of the plot, See the result in appendix B1.

3.7.7.2. Total operating time

Total digging time to complete the operation was recorded except turning and other downtime such as time for adjustment and machinery breakdown.

3.7.7.3. Fuel consumption

The fuel consumption was measured as per the standard method by observing the fuel required for traveling 40 m long distance. Using A known volume cylinder the fuel tank was filled up to some level by keeping the tractor on level land and after completing the operation, final measurement of cylinder was noted down. The volume of fuel used was taken as fuel consumed. The tank is filled to full capacity before and after each test trial. Amount of refueling after the test is the fuel consumption for the test. When filling up the tank, careful attention should be paid to keep the tank horizontal and not to leave empty space in the tank and See the result in appendix B3.

$$F=\frac{V}{T} \qquad \text{3.90}$$

Where: F is Fuel consumption, (L h^{-1})

V=Volume of fuel consumed, (L)

T= Total operating time, (h).

3.7.7.4. Theoretical field capacity

It is the rate of field coverage of the implement, based on 100 percent of time at the rated speed and covering 100 per cent of its rated width (Nasr *et al.*, 2019).

$$\text{Theoretical field capacity (ha/h)} = \frac{\text{Theoretical width (m) x speed (km/h)}}{10} \qquad \text{3.91}$$

3.7.7.5. Effective field capacity

It is the actual area covered by the implement, based on its total time consumed and its width. Rangapara (2014) expressed the relation of effective field capacity as:

Actual field capacity (ha/h) $= \frac{\text{area coovered ,ha}}{\text{time taken to cover the test area,h}}$……………………………………3.92

3.7.7.6. Potato seed damage test (%)

Seed damage test was carried out to know the percentage of damaged potato. After collecting to the exposing potato, number of damaged potato in the plot was calculated. In order to determine the damage percentage the following equation was used. The mass of potato crop is tubers, which have no bruise, or cutting for each of the mentioned samples, and the mass of damaged potato crop had only serious damage or neglected slight damage and See the result in appendix B4. The damaged tubers percent could be determined using the following formula (Nasr *et al.*, 2019).

Damage percentage% $= \frac{weight\ of\ damaged\ seed}{total\ weight\ of\ colected\ seed} \times 100$…………………………….....3.93

3.7.7.7. Draft and power requirement

a) Walking tractor drawn potato digger was operated at a recommended speed of 1.4 km/h, 2.0 km/h and 2.5 km/h.

b) Another tractor was used for pulling the two wheel tractor.

c) The spring type dynamometer was attached in between walking tractor and tractor.

d) Pull the walking tractor with the help of tractor during loaded condition and unloaded condition. Loaded condition is the tractor pulls the two-wheel tractor with the digger attachment, whereas unloaded condition is the tractor pulls the two-wheel tractor without attachment.

f) Record the readings and take sample three times.

g) (Rangapara, 2014) calculated Draft required to pull the digger.

Draft requirement (kgf) = $D_L - D_U$…………………………………………………..………..3.94

Where: D_L is draft required to pull 2WT in loaded condition, kg.

D_U= Draft required to pull 2WT in unloaded condition, kg

The power requirement (w) can be calculated as.

Power requirement (w) =draft(N)x speed($\frac{m}{s}$)……...3.95

3.7.7.8. Field efficiency

The field efficiency is the ratio of the effective field capacity to the theoretical field capacity, usually measured in terms of percentage (Nasr *et al.*, 2019).

Field efficiency (η), % $=\frac{EFC}{TFC} \times 100$………………………………..………………….……. 3.96

Where, TFC = Theoretical field capacity, ha/h

EFC = Effective field capacity, ha/h

3.7.7.9 Wheel slip

Wheel slip was calculated by recording total number of revolutions at no load and total number of revolutions at load. Wheel slip represents a loss of forward motion of the implement and it represents the loss of power, (see table B2). Wheel slip for any given load is determined by the expression of (Rangapara, 2014).

Wheel slip $= \frac{mo - m1}{mo} \times 100$………………………………………………………………3.97

Where, m_0 = wheel revolution with no pull

m_1 = wheel revolution with pull

3.7.8. Cost of operation of root crop digger

The total cost of the root crop digger was determined based on fixed and variable cost. The cost of operation obtained was compared with conventional practice of digging by hoe. Estimation of hourly operational costs of the digger was based on capital cost of the root crop digger, interest on capital, cost of repairs and spare parts, labor cost, and depreciation. The operational cost components of the prototype machine were estimated in Birr (ETB) by calculating the value of fixed cost and variable cost as following (Ashebir Tsegaye, 2015).

3.7.8.1. Fixed cost

It includes depreciation, interest, tax and insurance. According to the Kepner et al. (2005), the fixed costs was calculated as follows. Depreciation is a measure of the amount by which value of the machine decreased with the usage of the time.

$D = \frac{c - s}{l \times H}$………………………………………….………………………..…..…3.98

Where: D = Depreciation per hour, ETB/hr.

C = Capital investments, ETB

S = Salvage value, 10% of capital investment, ETB

L = Life of machine in hours or years

Interest is calculated on the average investment of the machine taking into consideration the value of the machine in the first and last year. The annual interest on the investment can be calculated.

$I = \frac{c \times s}{2} \times \frac{i}{H}$…………………………………………………………………….……………..…...3.99

Where: I = interest per hour, ETB/hr.

I = Interest per hour (10 % per year)

Insurance charge is taken based on the actual payment to the insurance; it taken as 1% of the initial cost of the machine per year.

3.7.8.2. Variable cost

Cost of repair and maintenance, fuel, lubricant and wage of the operator are variable costs. The repair and maintenance cost is a product of machine's cost price and repair and maintenance percentage factor (Kepner et al., 2005).

RM = 2.5 % × purchase price or capital investment per year………………..……………..3.100

Fuel cost is calculated based on actual fuel consumption for the operation. Wages of the operators are calculated based on actual wages of workers per hour. It differs from country to country. In addition, lubricants determined depending upon the maintenance cost or depending upon the oil price or oil consumption. Average lubrication cost is taken as 1.5% of fuel cost in ETB//hr. (Kamboj et al., 2012).

3.7.8.3. Total cost of operation per hour

The total cost per hour of the developed machine can be calculated by summation of total fixed cost per hour with total variable cost per hour.

Total Cost/hr. = Fixed Cost per hour + variable Cost per hour ………..…………..……… 3.101

CHAPTER FOUR

4. RESULTS AND DISCUSSION

Results were listed after all design, development and performance testing of prototype. Data of potato engineering property, damage of potato during the harvesting time, effect of speed on potato field capacity and damage of the crop during the field test was studied. The results and discussion of performance evaluation of the designed two-wheel tractor drawn single row potato digger were executed. Wheel slip for any given load is determined.

4.1. Details of two-wheel tractor drawn single row potato digger

The two-wheel tractor drawn one row potato digger encompasses, frame, digger blade, apron (separator), reciprocating ruler, camshaft, ground wheel. The separator unit was made of 21 (10 mm-round bar). These round bars are 21 in number, which has 60cm length and 2cm space between them welded to flat iron in the front and rear side. This part was connected to reciprocating ruler in order to separate soil and potato through oscillation. The blade was made of 3mm thick sheet metal. The digging capacity of the potato harvester was 1.4 ha/day. The ground wheel of the digger was adjusted cutting depth of the digger.

Power is transmitted from power tiler to the equipment was through belt and pulley, then the pulley is connected to the camshaft which creates offset distance in order to move the separator horizontally towards the blade by the offset distance of 3cm . The 30mm diameter of camshaft is connected to driven pulley at one end passing through the two 30mm diameter bearings and the offset cam at the other end to provide back and fro motion. The reciprocating ruler is made of 30x30mm squire pipe welded to the soil and potato separator.

The separation of soil and potato was made through the reciprocating mechanism by the 10mm round bar welded by 20mm spacing in order two pass the soil through that spacing and only left potato seed was thrown to the rear side of the digger.

4.2. Working principle of potato digger

The machine has pulley to transmit power from the engine to the potato digger's pulley connecting using v-belt. The pulley of the implement drives the shaft and this shaft convert the rotational motion to oscillatory motion of the separator (sieve). During the test experienced power tiller operator was selected and he was started the engine to begin the test of the digger by hitching the attachment of the digger. When the machine was started with the first treatment, which is 1.4 km/h speed. During the test the separator part of the digger was reciprocated to separate the soil and potato and shakes it, the engine delivered power to this part through belt transmission system.

4.3 Physical properties of soil of experimental site.

4.3.1 Moisture content and bulk density of soil

During field test soil physical property, mainly Moisture content was taken. In the carrying out of experiments, the soil conditions of the experimental field were studied and different parameters were calculated (Table 4.1). The soil of the field was sandy loam. Moisture content on dry basis of soil was measured by oven dry method. Five soil samples were taken randomly at different locations in the plot using manually core sampler of 6cm diameter and 10cm height.

Table 4. 1. Moisturecontent of the soil

S .no	Wt. of a soil(gm)	Wt. of soil after oven dry(gm)	Moisture content dry basis (%)	Moisture content wet basis (%)
1	600	521	15.16	13.16
2	585	519	12.72	11.28
3	591	520	13.65	12.01
4	593	516	14.92	12.98
5	601	523	14.91	12.97
Average	594	556.9	14.272	12.48

13.16%, 11.28%, 12.01%, 12.98% and 12.97 was results of Moisture contents from 5 different samples on wet basis respectively. The average moisture content of the experiment was found to be 12.48%.Sample of measured bulk density of soil was found to be 1843.5kg/m^3, 1836.5kg/m^3, 1840.0kg/m^3, 1882.5kg/m^3 and 1850.6kg/m^3 respectively (Table:4.1). Average value of moisture content and bulk density of experimental plot was found 12.48% (Wb) and 1850.62kg/m^3 respectively.

4.3.2. Physical property of potato

In order to optimize the design parameters of the potato digger it is important to measure potato Seed properties. The most important factors to be considered for selecting a suitable vibrator size for its better performance on exposing potatoes for picking manually are the physical properties of potato seed. The study of physical properties of potato seeds were conducted in eastern zone of Tigray and enderta areas of farmer's field. The seeds were measured its length and breadth as well as thickness by taking five samples of different size measured using Vernier caliper, reading of those samples were determined by arithmetic mean.

The dimension of the principal axes of potato seed was (L is length, B is the breadth and T is the thickness) of randomly selected potato, seeds were measured using digital Vernier caliper. The separator was designed based on the minimum diameter of the potato, So the mean length (L), breadth (B), thickness (T), size (S), of minimum potato was found as ranges from 39mm, 35mm, 30 mm, 34.47mm, respectively.

Table 4. 2. Size of potato

Group No.	Tuber size(e) m.	Tuber Length (L) mm.	Tuber Width (W) mm.	Tuber Thickness (H)mm.
1	52.21	73	50	39
2	50.71	69	45	42
3	46.09	68	45	32
4	34.47	39	35	30
5	47.27	60	44	40
Minimum	34.47	39	35	30
Maximum value	52.21	73	45	42

For designing the vibrator rod space of cup based on shape, surface area, sphericity mass and bulk density of the seed, need to be measured.

4.4. Testing of the digger

The performance of the prototype of the machine was evaluated in the farmer's field, after the potato leaves was burnt or removed, which can cause infection for the potato tuber and removed just to minimize the clogging of sieve-like round bars, which can separate potato from the soil. The operator was operated the machine according to the testing instruction of the machine, which means to attain the required capacity of the machine. The machine was tested in actual field conditions. At this time the recording of time was started to calculate the different parameter of the machine such as determination of field capacity of the machine, theoretical field capacity, actual field capacity, fuel consumption of the machine, digging efficiency, damaged potato and agronomic parameters such as row to row spacing. All the parameters has its own formula, equation and expression to evaluate the performance of diggers in order to make the machine available to small scale farm holders to enhance their life expectancy.

The following parameters were measured and recorded in the performance evaluation of the machine. The Power tiller drawn single row potato digger is suitable for digging and exposing tubers. It saves 88% labor and operating time and 6% on cost of operation compared to conventional method of manual digging with fork and hoe. The forward speed of the digger can vary up to 2km/hr. This is highly recommended to the potato grower and to custom hire service.

4.4.1. Laboratory test result

Table 4. 3. Specification of the digger

Particulars	Specifications
Type of machine	Power tiller driven potato digger
Separator unit round bar	10mm diameter, 600mm length
Overall width of blade	L = 600mm, w = 200mm and t = 3mm
Power transmission system	Belt – pulley system
Pulley	130 mm on main shaft (aluminum) 160mm on engine shaft (cast iron)
V belt	Average length of V belt 1440 mm
Number of V belt	2
Rotation speed of shaft	Average 1050rpm

4.4.2. Field test

Field test was carried out at eastern zone of Tigray regional state, in farmer's field. Three plot of lands size of 24m x 40m in each of the three blocks were selected for field testing. The test was conducted in well-prepared plot of land. The soil type of the field was sandy loam. The theoretical field capacity, effective field capacity, field efficiency, percent of damage, percent of un lifted potato and power requirement of potato digger was found out.

4.4.2.1. Result of tested parameters

The Field tests were carried out to get real data on the performance of the potato digger. The test was done in the western zone of Tigray regional state. The data obtained from field test was analyzed, in to tables and graphs by using software Microsoft Excel (2016). The performance of the two-wheel tractor drawn potato digger was tested at forward speeds of 1.4, 2.0 and 2.5 km/h. During field performance evaluation, the parameters determined was theoretical field capacity, effective field capacity, field efficiency percent of damage, percent of un lifted potato and power requirement of walking tractor operated potato digger with three replications of each. The detail data of these potato digger parameters are given in Appendix B.

Table 4. 4. Mean of measured performance testing of potato digger

Sr. No.	Parameters	Operating speed, km/hr		
		1.4km/hr	2km/hr	2.5km/hr
1	Fuel consumption, l/hr	1.30	1.31	1.21
2	Draft requirement, kg	63	68	72
3	Power Requirement, hp	0.322	0.348	0.368
4	Theoretical field capacity, ha/hr	0.19	0.25	0.34
5	Actual field capacity, ha/hr	0.162	0.2	0.26
6	Field efficiency, %	85.26	80	76.47

The theoretical field capacities were observed that 0.19, 0.245and 0.34 ha/h at an operating speed of 1.4, 2.0, and 2.5 km/hr respectively. The average actual field capacities were observed that 0.162, 0.2, and 0.26 ha/h at an operating speed of 1.4, 2.0, and 2.5 km/hr respectively. The field efficiency was also observed that 85.26%, 80 % and 76.47 % at an operating speed of 1.4, 2.0, and 2.5km/hr respectively.

4.4.2.2 Speed of the operation

The speed was measured using an instrument of a Tachometer. The speed of operation was found and carried on the speed limit at 1.4 km/h, 2 km/h and 2.5 km/h (Appendix Table B.1).The optimum speed of operation of 2WT drawn seed drill for digging potato was found to be 1.4 km/h, for a distance of 24m.

4.4.2.3 Fuel consumption

During operation, fuel consumption was observed as 0.84, 0.70 and 0.50 l/hr at the speed of 1.4, 2.0 and 2.5 km/h, and respectively. The fuel consumption result shown that, when the operating speed increased the fuel consumption rate also increased.

4.4.2.4. Draft requirement

The result shown that, draft requirement increased with increase in forward speeds with values 63, 68 and 72kg on speeds of 1.4, 2.0 and 2.5 km/h speed, respectively. The data presented in Table 4.4 indicates that the operating speed of the two-wheel tractor significantly affected the draft requirement.

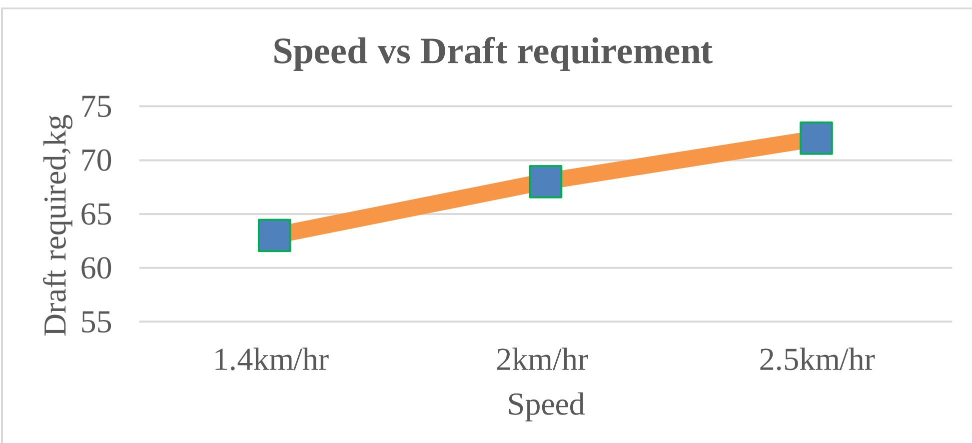

Figure 4. 1. Effect of forward speed on draft force

4.4.2.5. Power requirement

About 8.33 hp Power requirements was found maximum for speed at 2.5 km/h and minimum power requirement of 0.322 hp was observed for speed at 1.4km/h. The Fig 4.2 shows that the power requirement increased with increase in speed.

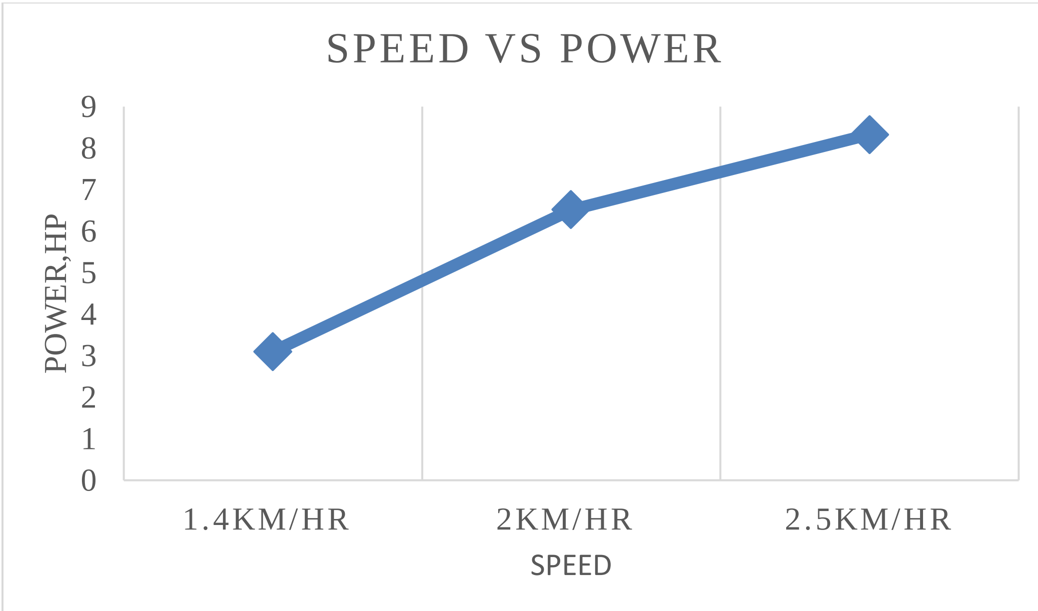

Figure 4. 2. Effect of Forward speed on power requirement

4.4.2.6. Wheel slip

The wheel slip of two-wheel tractor drawn potato digger was determined by using the method mentioned earlier and the results obtained for wheel slip data obtained at different operating speed was shown in Appendix B Table B.2. The wheel slip increased with increase in speed. The minimum wheels slip i.e. 4.98 % and maximum wheel slip i.e. 8.67 % was observed at speed of 1.4 km/h and 2.5 km/h, respectively. The Fig: 4.3 show that the wheel slip increased with increase in speed.

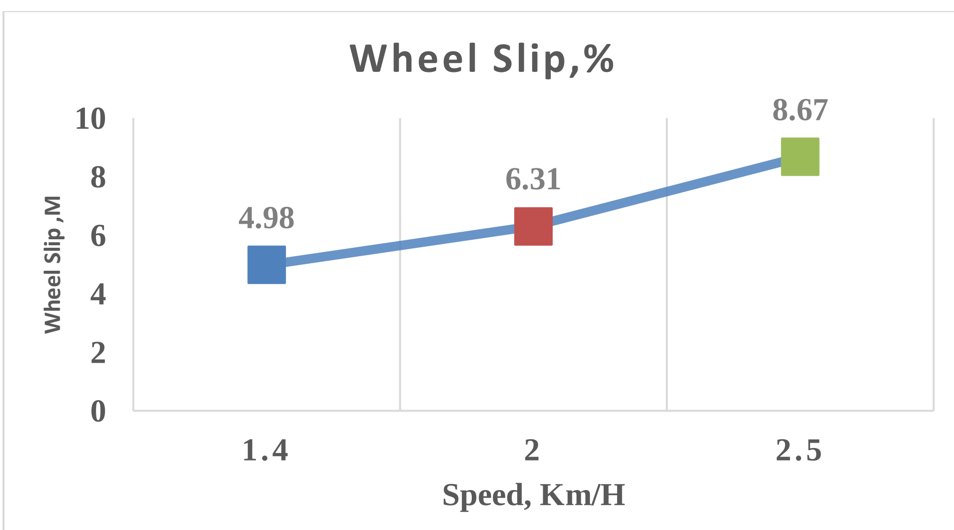

Figure 4. 3. Wheel slip result

4.4.2.7. Theoretical and effective field capacity

The mean values of theoretical field capacity and effective field capacity were obtained at different operating speeds shown in Table 4.4. The mean value of theoretical field capacity was observed at different speeds shown in the table above. The minimum value of theoretical and actual field capacity observed at 1.4 km/hr speed was 0.19 ha/hr and 0.162 ha/hr, as well as maximum values was observed at 2.5 km/hr speed was 0.34 ha/h and 0.26 ha/h respectively. The Fig: 4.4 show that both theoretical and effective field capacity increased with increase in speed.

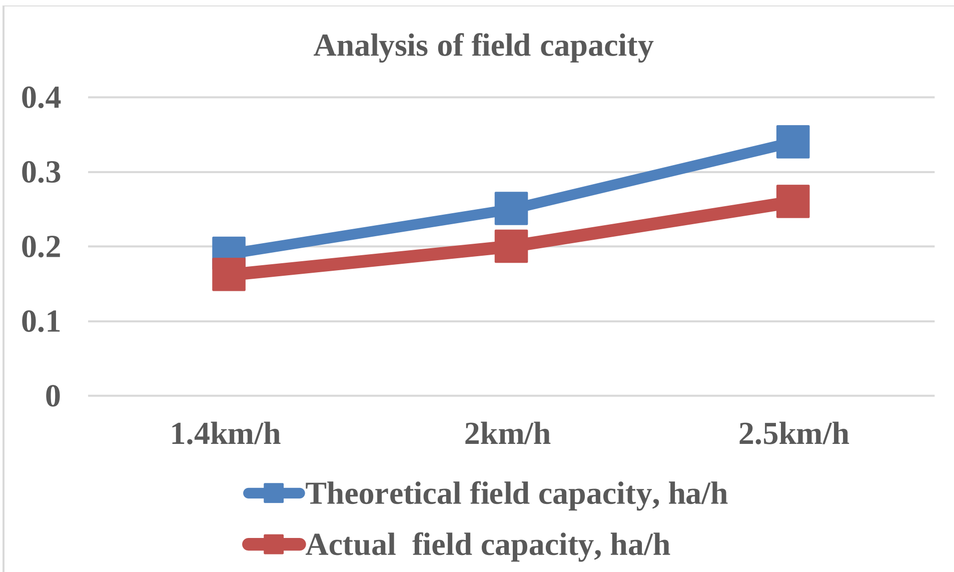

Figure 4. 4. Effect of forward speed on theoretical and effective field capacity

4.4.2.8. Field efficiency

The minimum and the maximum field efficiency were observed at different speed. The mean values of the field efficiency obtained were listed in the figure 4.4. The minimum field efficiency recorded at 2.5 km/hr operating speed was 76.47and the maximum field efficiency noticed that at a speed of 1.4 km/hr was 85.26 .This figure shows that field efficiency decreased with increased in speed.

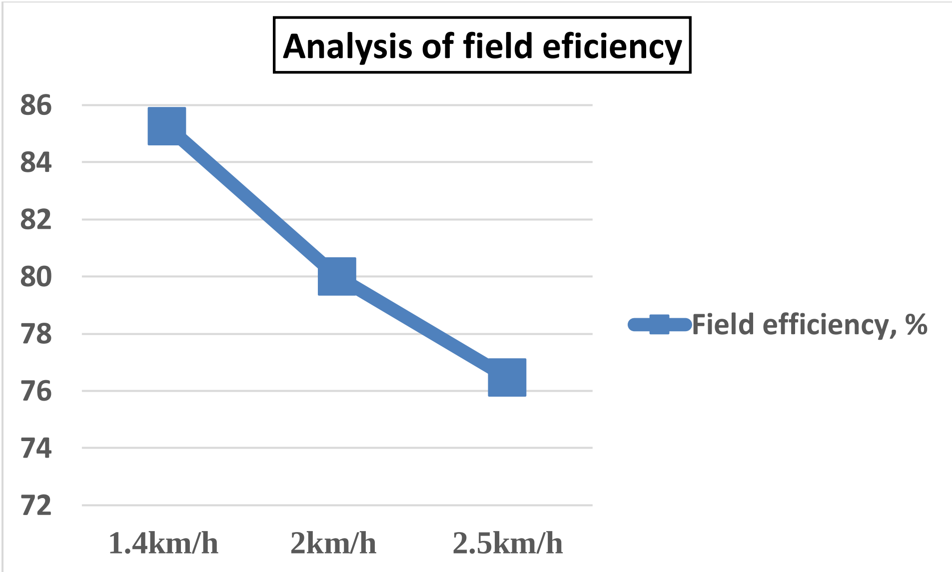

Figure 4. 5. Effect of forward speed on field efficiency

4.4.2.9. Effect of speed on exposed, undug and damaged potato seed

Three different operating forward speeds were found out. The 1.4 km/h, 2 km/h and 2.5 km/h forward speed was selected for digging operation and its effect of different operating speed on seed exposing, undug seed and seed damage was observed. The exposed potato was calculated to know how efficiently the oscillating conveyor was able to separate the potato from soil, how much of the potato remained undug (losses) and how much was damaged during the test. It was defined in the fig. 4.6 below.

Seed damages were observed that 5.3, 7.8 and 9.2% at an operating speed of 1.4, 2.0, and 2.5 km/hr respectively. The undug (losses) potatoes were observed that 8, 12.4 and 14% at speed of 1.4, 2.0, and 2.5 km/hr respectively.

This figure shows that percent of damaged seed was decreased with decreased in speed. Rangapara (2014) revealed that as the field size was decreased; number of passes of increased, which results to increase in time losses and gave lower values of field efficiency.

Table 4. 5. One way ANOVA of the effect of speed on the seed damage

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.950556	2	2.975278	153.0143	7.11E-06	5.143253
Within Groups	0.116667	6	0.019444			
Total	6.067222	8				

Table 4. 6. One way ANOVA of the effect of speed on the undug potato

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	57.22889	2	28.61444	104.2632	2.19E-05	5.143253
Within Groups	1.646667	6	0.274444			
Tota	58.87556	8				

Table 4. 7. One way ANOVA of the effect of speed on the dug potato

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	73.26889	2	36.63444	96.40643	2.75E-05	5.143253
Within Groups	2.28	6	0.38			
Total	75.54889	8				

Here's the decision rule for accepting or rejecting the null hypothesis: Since the P-value is smaller than the significance level (0.05) in the above three tables, we reject the null hypothesis that speed had no effect on damage, undug and exposed potato on the ground. And we conclude that the mean damage, undug and exposed potato in at least one treatment group differed significantly from the mean damage, undug and exposed potato in another group. The analysis of variance (ANOVA) revealed that it was 95% confident that the mean speed had significantly affected the damage, undug and exposed potato.

4.4.2.10. Labor requirement

The potato digger was required two persons for collecting and operation of digging of potato on the well-prepared land. The first person was required for to perform a digging operation i.e. skilled labor for operator of the two-wheel tractor, while the second one required for collecting the exposed potato on the ground in to sack.

4.4.2.11. Economical evaluation

In the digging operation using the prototype one row digger, two persons were participated: one to collect the exposed potato and the other to operate the machine. However, manual of the time required to harvest potato from a hectare of land using manual method, eight persons, was 68.575 hours. While, a single person, using mechanical potato digger, required only 5.7 hours/ha to do the same work. Hence, 62.86 reduce the time requirement per hectare in hour. Labor requirement reduced by the same amount when the prototype digger was used. However, mechanical potato digger which is estimated to be 29073.43 Birr Appears to be high for a single farmer to own the machine. By renting, farmer can save time and effort to provide leisure time to do the form operations.

4.4.2.12. Cost of operation

The unit cost of a two-wheel tractor drawn one-row potato digger was determined by calculating the cost of different components and their fabrication cost as given in Appendix-C. The estimated cost of the one unit of two-wheel tractor drawn one row potato digger was determined as 29073.43 ETB.

Table 4. 8. Cost operation and cost of machine

No	Cost Variables	Summary
1.	Raw Material Cost	14000 ETB
2.	Material Wastage 2.5%	1325.30 ETB
3.	Machine Cost	2593 ETB
4.	Labor Cost	4700 ETB
5.	Overhead Cost 5%(3+4)	364.65 ETB
6.	Profit 10 %(A+B+C+D+E)	2298.295 ETB
7.	Sells Tax 15 %(A+B+C+D+E +F)	3792.1875 ETB
	Total Selling Price	29073.43ETB

4.4.2.13. Result of calculation part

Table 4. 9. Total weight calculation

Available DBHP(draw bar horse power), hp	9
Available Draft, N	17,215
The total draft required to dig, N	2118.96
Thickness of the blade, mm	3
Weight of the soil on the blade, N	508.5
Bending moment of the blade, Nm	152.5
Maximum bending moment of shaft, Nm	88.6
Diameter of the shaft, mm	30
Belt length, m	1.44
Belt Velocity, m/s	10.9
Torque on the shaft, Nm	40
Output Power at shaft, W	4398

Efficiency of the power, %	65.5
Force of belt, N	403.5
Tension at the tight side of belt, N	1233
equation (3.21),	
Tension at the slack side of belt, N	828.5
centrifugal force, N	411
Number of rod required	20

Over all weight of the frame			
Over all weight of squire pipe in the frame		**Over all weight of the sheet metal in the frame**	
Area, m^2	0.63744	Area	0.1088 m^2
Volume, m^3	0.00191232	Volume	0.000312 m^3
Density, kg/m^3	7870	Density	7870 kg/m^3
Mass, kg	15.05	Mass	2.45544 kg
Over all weight of the flat iron in the frame		**Over all weight tube(shaft holder)in the frame**	
Area	0.06596 m^2	Area	1256mm^2
Volume	0.0001164 m^3	Volume	125600mm^3
Density	7870 kg/m^3	Density	2710kg/m^3
Mass	0.916068 kg	Mass	0.34kg
Over all weight of angle iron in the frame		**Over all weight of the (flat iron) in the separator sieve**	
Area	0.848 m^2	Area	0.118864m^2
Volume	0.00030528 m^3	Volume	0.002097 m^3
Density	7870 kg/m^3	Density	7870 kg/ m^3
Mass	2.4 kg	Mass	1.65kg
Over all weight of the (round bar) in the separator sieve		**Over all weight of the rear and front part of longitudinal (flat iron)**	
Area	0.4758m2	Area	0.124m2
Volume	0.001189 m^3	Volume	0.000248m3

Density	7870 kg/m^3	Density	7870kg/m3
Mass	9.36kg	Mass	1.95 kg
Over all weight of the metal wheel		**Over all weight of the reciprocating ruler**	
Area	0.17688m2	Area	0.08352m2
Volume	0.0004824m3 m^3	Volume	0.00016704 m3
Density	7870kg/m^3	Density	7870km/m3
Mass	3.79kg	Mass	1.31kg
Over all weight of the spoke in the wheel		**Over all weight of the pulley**	
Area	0.046m2	Area	0.0161m^2
Volume	0.000228 m3	Volume	0.0013m^3
Density	7870kg/m3	Density	2710kg/m^3
Mass	1.8 kg	Mass	3.52kg
Over all weight of the shaft		**Over all weight of the blade**	
Area	0.0014m^2	Area	0.24m2
Volume	0.00028m^3	Volume	0.00036m3
Density	7870kg/m^3	Density	7870kg/m^3
Mass	2.22 kg	Mass	2.83kg
Over all weight of the groove in the pulley		**Over all weight of the pulley**	
Area	0.0392m2	Area	0.073m2
Volume	0.0000576m3	Volume	0.00155m^3
Density	2710kg/m3	Density	2710 kg/m3
Mass	0.156kg	Mass	4.2kg
Total area of the pulley		4.2kg-0.156kg=4.05kg	
Weight of stand for the two round bar		**Weight of stand for the two squire pipes**	
Area	0.00181m2	Area	0.2164m2
Volume	0.0001646m3	Volume	0.0003246m3
Density	7870kg/m3	Density	7870kg/m3
Mass	1.3kg	Mass	2.55kg
Total mass components of the digger		61.69kg	
Total weight of components of the digger		605.18N	

CHAPTER FIVE

5. SUMMERY, CONCLUSION AND RECOMENDETION

5.1 Summery

This study was concerned on design development and performance testing of two-wheel tractor drawn on row potato digger. The power transmits from 15hp power tiller through the v-belt by connecting drive pulley from the power tiller to the driven pulley on the digger. Shaft was inserted to the driven pulley which is rotated by the belt later changed this motion to reciprocating motion using offset mechanism. The rod type separator Consist of straight steel bars linked together with gaps to enable soil and debris to be shake with adjustable agitation. Operator must ensure that agitation is minimal to avoid tuber damage. The agitation process was done by placing an elliptical type of cam rounding freely in the camshaft and this cam is connected to arm. Because of the rounding of the pulley the rods moves linearly with constant speed (v). The separator takes its movement from the flywheel; motion transmission between them was done using a circular pulleys and V-belts.

Frame is the upper part, which accommodated all the attachments and accessories of the digger. It was made up of squire pipe mild steel of dimensions 0.87 m x 0.50 m x 0.065 m respectively, as length x breadth height. The frame attaches to the blade, separator shaker and the pulley of the digger.

The two-wheel tractor drawn one row potato digger has the following benefit:

- The potato digger is a low cost machine, which can be afford by small-scale farmers.
- It can easily be maintained and manufactured by farmers and local artisan
- Even untrained operator can operate a two-wheel tractor drawn one-row digger.
- It has better exposing potato to the ground.
- It reduces human drudgery compared to manual operation.

The study had the following objectives.

- To study the physical properties of potato
- To design and development two-wheel tractor drawn one row potato digger
- To evaluate the performance of two-wheel tractor drawn one row potato digger

The dimension of the principal axes of potato seed was (L is length, B is the breadth and T is the thickness) of randomly selected potato, seeds were measured using digital Vernier caliper. Size, surface area and sphericity were calculated. The mean length (L), breadth (B), thickness (T), size (S), surface area (SA) and sphericity (Sp) of randomly selected potato was found ,39 mm, 35mm, 30mm,34.47mm , 2995.9mm2 and 88.38 percent respectively. These physical properties were considered and accordingly a two-wheel tractor drawn one-row potato digger was developed.

The Two-wheel tractor drawn single row potato digger_encompasses, frame, digger blade, apron (separator), reciprocating ruler, camshaft, ground wheel. The separator unit made of 21 (10mm round bar) and has 60cm length each welded to flat iron column in the front and rear side. The 21 round bars were 2cm apart each other, to pass the soil below the separator and the potato above the separator. This part was connected to reciprocating ruler in order to shake the separator to separate soil and potatoes. The blade had 30cm wide and 50cm long, and this length is equal to the one row spacing of the potato field and this was made of 3mm thick sheet metal attached to the frame of thee digger.

The digging capacity of the potato harvester was 1.4 ha/day. The depth of cutting of the digger was adjusted by the ground wheel of the digger and the power is transmitted from power tiler to the implement is through belt and pulley, then the pulley connected to the camshaft which creates offset distance in order to move the separator horizontally towards the blade by the offset distance of 3cm . The 30mm diameter of camshaft was connected to driven pulley at one end passing through the two 30mm diameter bearings and the offset cam at the other end to provide back and fro motion. The reciprocating ruler was made of 30x30mm angle iron welded to the soil and potato separator. The two ends of reciprocating ruler were attached to the frame using bolt and tightened nut. The driven pulley was made of aluminum contains two groove to transmit power using two v-belts and 30mm diameter 40cm long shaft was inserted to it.

A depth adjustment was made for digger blade with the help of ground wheel. A draw bar link was fabricated for attachment for pull of the developed two-wheel tractor drawn potato digger.

The field-testing of two-wheel tractor drawn wheat drills was carried out at farmer's field. Three plots of 24m × 40 m (size) were selected for field test. In the test two-wheel tractor drawn potato digger was operated with 1.4, 2 and 2.5 km/h speed.

Two-wheel tractor drawn potato digger was operated on these three speeds and its effect on the potato damage, fuel consumption, field capacity, field efficiency, draft requirement and power was observed during operation, fuel consumption was observed as 0.84, 0.70 and 0.50 l/hr at the speed of 1.4, 2.0 and 2.5 km/h, respectively. The fuel consumption result shown that, when the operating speed increased the fuel consumption rate also increased.

The draft requirement result shown that, draft requirement increased with increase in forward speeds with values 63, 68 and 72kg on speeds of 1.4, 2.0 and 2.5 km/h speed, respectively.

About 8.33 hp Power requirements was found maximum for speed at 2.5 km/h and minimum power requirement of 3.1 hp was observed for speed at 1.4km/h. This data shows the power requirement increased with increase in speed.

The mean values of theoretical field capacity and effective field capacity were obtained at different operating speeds. The minimum value of theoretical field capacity observed at 1.4 km/hr speed was 0.19 ha/hr and maximum values was observed at 2.5. This shows as theoretical and effective field capacity increased with increase in speed.

The minimum field efficiency recorded at 2.5 km/hr operating speed was 76.47and the maximum field efficiency noticed that at a speed of 1.4 km/hr was 85.26. Seed damages were observed that 5.3, 7.8 and 9.2% at an operating speed of 1.4, 2.0, and 2.5 km/hr respectively. The undug (losses) potatoes were observed that 8, 12.4 and 14% at speed of 1.4, 2.0, and 2.5 km/hr respectively.

At 1.4 km/h operating speed, seed damage and fuel consumption was properly maintained as per requirement and was selected for digging operation as it gives better results than the other operating speed. Field performance tests were carried out to obtain actual data on overall performance of two-wheel tractor drawn potato digger. The theoretical field capacity, effective field capacity and field efficiency was observed 0.19 ha/h, 0.16`ha/h and 85.26% respectively. During 1.4 km/h operating speed. The power required for operating the potato digger in the field found 3.1 hp. The wheel slip was 4.98 % occurred.

5.2 Conclusions

A Two-wheel tractor drawn one-row potato digger has been designed and fabricated with locally available materials to match the need and alleviate the difficulties of small and medium scale farmers.

The following conclusions were made from the study of developed two-wheel tractor drawn one row potato digger.

- Two-wheel tractor drawn potato digger performs satisfactory works in the field with required seed exposing, uniformity with minimum damage of tuber.
- It shows good digging performance the test conducted at working speed of 1.4 km/h, 2 and km/h, 2.5 km/h, but 1.4 km/h had better digging performance result.
- The theoretical field capacity and actual field capacity were 0.19 ha/h and 0.162 ha/h, and the average field efficiency was 85.26 percent at average speed of 1.4 km/h.
- The estimated cost of the two-wheel tractor drawn one row potato digger was determined as 29073.43 ETB. The performance of two-wheel tractor drawn one row potato digger was good for working in the clay loam soil.

5.3. Suggestions for future work

To improve the performance of 15 hp power tiller driven one row potato digger, it is essential to explore the following suggestions.

- The machine was developed for harvesting potato, it is possible to redesign for other root crops, carrot, onion, bit and groundnut tested for these similar crops and feedback received will be used for further design refinements, if any.
- It should be developed to tractor-drawn by increasing the number of row to get more output.
- The number of rows covered should be increased to improve field capacity and field efficiency of developed two-wheel tractor drawn potato digger.

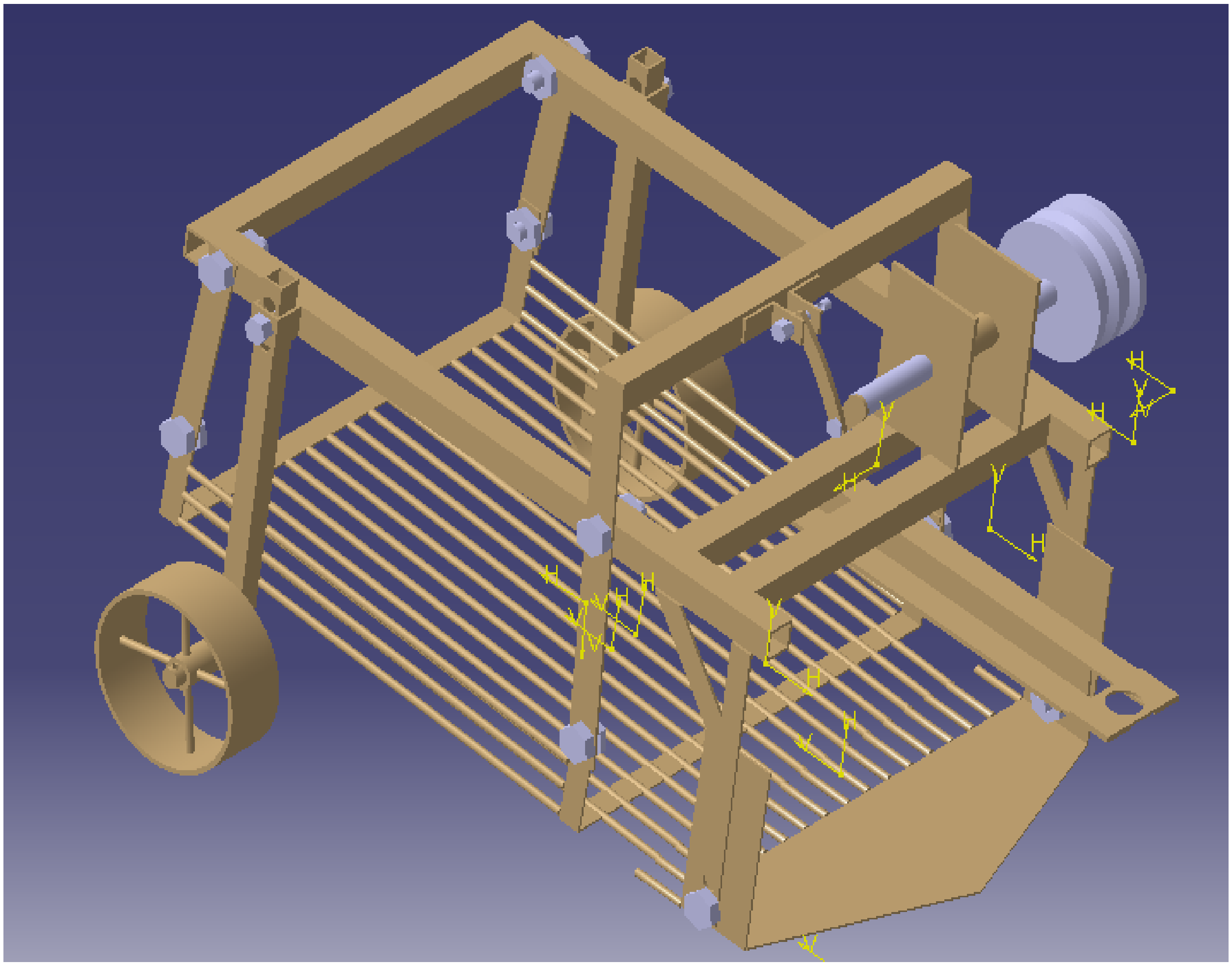

Figure 5. 1. Full picture of the digger

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APPENDICES

Appendix A

Physical properties of potato Sample calculations

1. M.d (mm) $=\sqrt[3]{(breadth\ \times length \times\ thickness\ )}$

$$\text{m.d (mm)} = \sqrt[3]{(35\ \times 39\ \times 30)}$$

$$= 34.47 \text{ mm}$$

Exposed potato, %$=\frac{V}{H+V} \times 100$...3.31

Un-dug potato, %$= \frac{U}{H+U+V} \times 100$……………………………………………………………..3.32

Where: U is the total number of un-dug potato (dug manually after the operation of root crop digger)

Theoretical field capacity (ha/h) $=\frac{\text{Theoretical width (m)} \times \text{speed (km/h)}}{10}$.......................................3.33

Actual field capacity (ha/h) = $\frac{\text{area coovered ,ha}}{\text{time taken to cover the test area,h}}$...3.34

Damage percentage % $= \frac{\text{weight of damaged seed}}{\text{total weight of colected seed}} \times 100$ ....…...3.35

Field efficiency (η), % $=\frac{\text{EFC}}{\text{TFC}}\times 100$………………………………………………….……...….3.36

Table A1. Measured physical properties of potato

Group No.	Tuber size(s) mm	Tuber Length (L) mm.	Tuber Width (W) mm.	Tuber Thickness (H) mm.
1	52.21	73	50	39
2	50.71	69	45	42
3	46.09	68	45	32
4	34.47	39	35	30
5	47.27	60	44	40
Minimum value	34.47	39	35	30
Maximum value	52.21	73	45	42

Appendix B

Field test

Table B1. Results from the field-test

Rep	Distance of test(m)	Speed(km/hr)	Time taken(s)	Loss time(s)	Cutting width (cm)	Fuel consumption (l/hr)	Fuel consumption(ml)	TFC(ha/h)	EFC(ha/h)	EF,%
1.	40	1.39	114	10	60	1.26	43.4	0.083	0.070	85
2.	40	1.40	109	9	60	1.33	43.5	0.084	0.073	87
3.	40	1.41	110	10	60	1.30	43.3	0.085	0.072	85
Mean		1.4	111	10		1.30	43.4	0.084	0.076	86
1)	40	2.0	97	9	60	1.47	34.8	0.12	0.099	83
2)	40	2.08	96	9	60	1.27	37.0	0.125	0.102	82
3)	40	2.1	101	8	60	1.20	36.2	0.126	0.101	80
Mean		2.06				1.31	36	0.124	0.17	82
1	40	2.47	72	5	60	1.32	28.2	0.148	0.110	74
2	40	2.52	72.4	8	60	1.23	27.4	0.150	0.108	72
3	40	2.51	79	6	60	1.08	25.4	0.150	0.102	68
Mean		2.5				1.21	27	0.15	0.139	72

Table B2. Result of Wheel slip

speed	Rep.	Distance covered in 10 revolutions		Wheel slip,%
		With load, m	Without load, m	
1		9.82	9.35	5.02
2	1.4	9.86	9.40	4.92
3		9.89	9.42	5.00
mean		9.85	9.39	4.98
1		10.10	9.50	6.32
2	2	10.12	9.53	6.19

3		10.09	9.48	6.41
mean		10.10	9.50	6.31
1		10.43	9.61	8.49
2	2.5	10.47	9.63	8.69
3		10.47	9.62	8.83
Mean		10.46	9.62	8.67

Table B3. Mean of measured performance testing of potato digger

Sr. No.	Parameters	Operating speed, km/hr		
		1.4km/hr	2km/hr	2.5km/hr
1	Fuel consumption, l/hr	1.30	1.31	1.21
2	Draft requirement, kg	63	68	72
3	Power Requirement, hp	3.1	6.52	8.33
4	Theoretical field capacity, ha/hr	0.19	0.25	0.34
5	Actual field capacity, ha/hr	0.162	0.2	0.26
6	Field efficiency, %	85.26	80	76.47

Table B4. Effect of speed on potato damage

S.no	Speed		
	1.4 km/hr	2 km/hr	2.5 km/hr
1	5.5	7.9	9.3
2	5.3	7.85	9.1
3	5.1	7.65	9.2
Mean %	5.3	7.8	9.2

Table B5. Field data of exposing potato on the ground

S.no	Speed		
	1.4 km/hr	2 km/hr	2.5 km/hr
1	86.2	81.6	80
2	86.5	82.1	78.6

3	86	83.1	79.2
Mean %	86.7	82.8	79.8

Table B6. Field data of harvesting loss

S.no	Speed		
	1.4 km/hr	2 km/hr	2.5 km/hr
1	8	12.5	13.7
2	7.9	12.6	14.8
3	8.1	12.1	13.5
Mean %	8	12.4	14

Appendix C

Construction and operational costs of the potato digger

Table C1. Materials of the potato digger and their costs

No:	Type of Materials	Size	pcs	cost
1	shaft	Ø 30x 400mm	1	994
2	Sheet metal	6x200x200mm	2	600
3	Squire pipe	4x2900mmx40mm	1	4000
4	Bearings,	P204	2	1000
5	Sheet metal	6X560X200mm	1	1400
6	Round bar	Ø 10x 400mm	2	1300
7	Sheet metal	4x30 x400mm	1	1000
8	bolts, and nuts	M-8x80	8	490
9	Belt	B-61	2	336
10	pulley (aluminum)	Ø24x70mm	1	2000
11	Cotter pin	Different sizes	6	280
12	electrode	2.5	2	600
13	Total material cost	14000		

Table C2. Machine and labor cost

No:	Item description	Unit	Machine cost/ hr	Working hrs	Total Cost	Labor cost/hr	Working hour	Total cost
1	Cutter	Hr	16	64	1024	25	64	1600
2	Grinder	Hr	10	20	120	25	20	500
3	Bending machine	Hr	3.5	4	14	25	4	100
4	Lathe	Hr	13	60	780	25	60	1500
5	Driller	Hr	5	25	125	25	25	625
6	Welding	Hr	30	15	450	25	15	375
			Subtotal		2593			4700
	Machine and labor cost Total							7163

Table C3. Cost of summery

No	Cost Variables	Summary
8.	Raw Material Cost	14000 ETB
9.	Material Wastage 2.5%	1325.30 ETB
10.	Machine Cost	2593 ETB
11.	Labor Cost	4700 ETB
12.	Overhead Cost 5%(3+4)	364.65 ETB
13.	Profit 10 %(A+B+C+D+E)	2298.295 ETB
14.	Sells Tax 15 %(A+B+C+D+E +F)	3792.1875 ETB
15.	Total Selling Price	29073.43ETB

Table C4. Calculation of cost of operation of potato digger per hour

Cost of machine (c)	29073.43 ETB
Assumption	
Life of machine (L), years	8
Annual working hours (H), hr.	2160
Salvage Value (S)	10% of capital cost

Interest rate	10 % percent per annum
Fuel cost	1620birr for testing
Wage per day of 8hr	200 birr
	A. Fixed cost
Depreciation (D), ETB/hr.	D = $\frac{c-s}{l\ x\ H} = \frac{29073.43 - 2907.343}{8\ x\ 2160}$=1.514 ETB/h
Interest	I =$\frac{cxs}{2}$x$\frac{i}{H}$ $=\frac{29073.43ETB+2907.343ETB}{2}x\frac{0.1/year}{2160\ hr/year}$ =0.74 ETB/hr
Taxi and insurance	TI = 1% of the initial cost of the machine per year 0.01 x 29073.43 ETB x $\frac{1}{2160hr}$=0.13ETB/hr
Total fixed cost, ETB/h	I+D+TI =0.13birr/hr+1.514birr/hr+0.74Birr/hr=2.39 birr/hr
	B. variable cost
Fuel cost l/h, birr/hr=one litter 18	FC=5 lit/hr=18birr/lit=90birr/hr
1) Lubrication cost at 1.5%	Lc=1.5% fuel cost Lc=1.5%x90birr/hr=1.35 birr/hr
2) Repair and maintenance cost 2.5% of initial cost	RM=2.5% x29073.43 birr x0.001 or /2160hrx8=0.042birr/hr
3) Wedge of the operator, birr/hr	25 birr/hr
4) Total variable cost	90 birr/hr+1.35+0.042birr/hr+25birr/hr=232.8 birr/hr
5) Total cost of the machine	Fixed cost +variable cost=2.4birr/hr +232.8birr/hr =235.2birr/hr

Appendix D