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GHANA

Design, Construction and Evaluation of a Tractor-Mounted Groundnut Harvester

by

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DECLARATION

I hereby declare that this submission is my own work towards the Master of Science (Agricultural Machinery Engineering) degree and that, to the best of my knowledge, it contains no material previously submitted for the award of any degree in the University, nor material previously published, except where due acknowledgement has been made in the text.

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ABSTRACT

Groundnut harvesting is a laborious operation especially on large-scale farms when the soil is dry and hard. Under such conditions, high losses ensue during harvesting because of inappropriate groundnut harvesting implements. The study sort to address this problem by designing a two row fully mounted groundnut harvester. Locally available materials were used for the construction of a tractor-mounted groundnut harvester. Four alternative designs were proposed and analysed based on the set criteria (safety, ease of fabrication, cost and ease of servicing) and the best among the designs was selected. The design was evaluated comparing the vine and pod yield, percentage pod loss, damaged pods and 1000-seed weight with four other harvesting methods (hand hoe, hand fork, hand pulling and cutlass). The experiment was carried out using a randomized complete block design comprising three blocks and five treatments. Results were analysed using analysis of variance at 95% confidence level. The tractor-mounted harvester recorded a vine and pod yield of 1833 kg/ha and a total percentage pod yield loss of 25.64% constituting 0.19% and 25.45% damaged and detached pod losses respectively compared with the hand hoe, cutlass, hand pulling and hand fork methods of harvesting. Groundnuts harvested with the tractor-mounted harvester recorded an average 1000-seed weight of 360 g second to hand fork harvesting with 394 g seed weight. Owing to the high losses of the harvester, it is recommended that the tractormounted harvester be modified to optimise and improve performance.

DEDICATION

This work is dedicated to the Almighty God for his providence and mercy. To my wife, Mrs. Ophelia Alubokin for her support and encouragement. To my parents Margaret Anyigrah and Sebastian Alubokin. Also to my entire family and friends for their immense support and encouragement in diverse ways.

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Ghana is one of the leading producers of groundnuts in the world. Ghana is ranked 14th with a total production volume of 426,280 tonnes of in-shell groundnuts in the world, seventh in Africa and forth in West Africa (FAOSTAT, 2014). Groundnuts is the most important legume crop grown in Ghana, about 475.1 metric tonnes in terms of the total production (MoFA, 2013).

Despite the numerous importance of groundnuts, yields of 1,276 kg/ha obtained in Ghana is relatively low as compared to a yield of about 4,407 kg/ha in the developed countries such as the United States (FAOSTAT, 2014). Generally, low groundnut yields in Ghana was initially attributed to the low yielding varieties available, a problem being resolved by the National Agricultural Research Systems as there are now several high yielding, heat tolerant and disease free released groundnut such as the *Edorpo-Munika* and *Nkatie-sari* (Frimpong *et al.,* 2006. and Padi *et al.,* 2006). The Crop Protection Programme of the Savannah Agricultural Research Institute released high yielding groundnut varieties to farmers in order to increase productivity, yet the yields of groundnuts from many farmers were observed to be lower than expected.

Ghanaian improved varieties of groundnut mentioned by Kombiok *et al*. (2012) intended to increase production were the *Chinese* (maturing in 90 days), *Manipinta* (semi-erect type maturing in 120 days) and *Nkatie-Sari* (erect or bunch type) maturing in 110 days, which are obtainable from the Groundnut Improvement Programme of Savannah Agricultural Research Institute.

Groundnut harvesting consists of the removal of the plant with the pods from soil and carried out in bright sunshine so that vines together with pods can be dried in the field (Vagadia *et al*., 2015). Groundnut harvesting in Ghana is mostly by hand pulling and becomes difficult when the soil becomes dry resulting in pod yield losses. The dry and hard state of the soil would often require working the soil before harvesting (Kombiok *et al.*, 2012 and Tsigbey *et al*., 2003).

Kaul (1978) stated that groundnut harvesting goes through a number of operations. It is made up of digging, lifting of the groundnuts, windrowing on the field, stocking and threshing. Among field operations that have to do with groundnut cultivations, harvesting is the most laborious and costly endeavour.

Harvesting is the most mechanized operation of groundnut production in developed countries replacing manual labour for harvesting and several designs of harvesters are available to farmers. Harvesting constraints in less-developed countries is commonly caused by the nonavailability of tools for digging groundnuts plants from the ground. (Nautiyal, 2002).

1.2 Statement of the Problem

Harvesting is a significant operation in the cultivation stages of groundnuts. The ease and means of harvesting is essential to moving away from subsistence farming to commercial groundnut production. According to Tsigbey (2003), groundnut harvesting is a laborious function to perform, especially in the event that the rains cease early. In some instances, farmers resort to carrying water from afar to their farms to wet the soil before hand pulling. This condition of the soil often results in severe pod loss. Kaul (1978) wrote that the traditional method of harvesting groundnut in Nigeria is with a hand hoe, digging through the ridge. This is labour intensive when the process is carried out at a soil moisture content of 12 % to 15 %.

According to Kombiok *et al.* (2012), harvesting of groundnuts is carried out by pulling the plant out with the hand or digging the plant out from the soil with a hand hoe in the Northern savannah zone of Ghana. Therefore, most of the issues relating to harvesting mentioned earlier, which are often addressed by mechanical harvesters, remains a problem. Kaul (1978) noted that, the variety of groundnut cultivated affects the method(s) of harvesting employed. He again noted that, when crops have grown past the stage of physiological maturity and hardening of the soil sets in, it becomes difficult to harvest. In such circumstances, it becomes important to harvest by loosening the soil either by working with a plough, a blade harrow usually along the plant rows or working with a hand hoe.

The difficulty of harvesting is more profound with certain varieties of groundnut, which is the spreading type of groundnut. The process of up-rooting the crop from the soil is a rather difficult operation as pod formation takes place all along the creeping branches of the plant and their pegs are comparatively thinner and more delicate (Kaul, 1978). The attendant difficulties of hard soil and harvesting losses associated with the field operation of harvesting groundnuts, especially during drought coupled with the high cost and tedious nature of groundnut harvesting ought to be addressed, thus the need to design a groundnut harvester.

1.3 Significance of Study

In an attempt to address the problem of harvesting groundnuts more efficiently, reducing labour inputs and increasing overall productivity, various researchers have looked at resolving the matter.

Groundnut cultivation in Ghana experienced a decline from 475056.00 tonnes to 408814.00 tonnes in production from 2012 and 2013 respectively, but increased in production in 2014 by 426280.00 tonnes relative to 2013 production year (FAOSTAT, 2014). Groundnuts cultivation is a source of income and livelihood for the people of the three Northern Regions of Ghana reported in Tsigbey (2003) research and as such, an increase in the volumes of production of groundnuts through mechanised harvesting would greatly increase the income levels of inhabitants of the Northern Regions.

According to Fonteh (2010), there are 947 serviceable tractors within the three northern region of Ghana. This accounts for 55% of the total tractor population in the Ghana. The availability of animal power and it wide usage for tillage in the three northern regions of Ghana makes it imperative to look at mechanised harvesting of groundnuts. The execution of harvesting by the bullock-drawn digger is observed to be acceptable and economical when compared with manual harvesting of groundnuts. There are several notable models of groundnut harvesters for purchase, with prime mover being either animal draught or power tiller drive, with horsepower ranging between 2.24 kW (3 hp) to 4.47 kW (6 hp). Designed groundnut diggers have recorded field capacities ranges from 1.2 ha/h for animal drawn to 1.5 ha/h for a power tiller in Nigeria (Kaul, 1978).

Negrete (2015) reported that low productivity in groundnuts production to a large extent is attributed to the lack of development of groundnut harvesting technology, which makes it difficult for farmers to consider importing or adopt local mechanized approach to cultivating groundnuts. Negrete (2015) also wrote that mechanised cultivation of groundnut would reduce cost of production and the influence on pricing of the commodity and market uncertainties as well as increase productivity and increase the volumes of production.

The modernisation of agriculture resulting in a structural transformation of the economy, evident in food security, employment opportunities and poverty reduction, is the national agenda for the agricultural sector (MoFA, 2007). The world's largest producers of groundnut have transformed their economies owing to the use of harvesting implements during crop production (Negrete, 2015).

According to Tsigbey (2003) and Pandmanathan *et al.* (2006), the major reasons for the demand for groundnut machinery are to reduce drudgery, to reduce production timelines, and to increase productivity and income. It is projected that a 10% increase in tractive power, and a 15% rise in speed would necessitate a 25% decrease in daily working hours (Kaul, 1978).

1.4 Aim and Specific objectives of Study:

The aim of the study was to design, construct and evaluate a tractor-mounted groundnut harvester. The specific objectives of the study were:

1. to design and construct a tractor-mounted groundnut harvester
2. to determine the vine and pod yield (kg/ha) of five(5) harvesting methods
3. to compare the percentage pod yield losses of five (5) harvesting methods 4. to compare the 1000-grain weight of five (5) harvesting methods

CHAPTER TWO

LITERATURE REVIEW

2.1 Groundnut Plant and Varieties

Groundnut, commonly known as the poor man's nut is one of the world's important food crop and oil seed. It is indigenous to South America and has never been found uncultivated. Arachis *hypogaea* (of the *leguminocae* family) is the botanical name of groundnuts, which is derived from two Greek words, *Arachis* meaning a legume and *hypogaea* meaning below ground, pertaining to the development of pods in the soil (Pattee and Young, 1982). Groundnut is an upright or prostrate annual plant and widely grown in the tropical, subtropical and warm temperate zones of the globe. Extensive ethnologic studies of the major Indian tribes of South America recorded a widely diffused culture of groundnut use and showed collateral prove for its domestication long before the Spanish Conquest. When the Spaniards returned to Europe, they returned with groundnuts. Later traders were credited with the spreading of groundnut to Asia and Africa where it is routinely cultivated between the latitudes 40°N and 40°S (Pattee and Young, 1982).

Amber and Katrina (2004) wrote that there were two fundamental categories of groundnut: groundnut indigenous to America (Arachis *hypogaea*) and Bambara nuts that is indigenous to Africa (Voandzeia *subterranae*). Their research however mentions four distinct types of the America groundnuts; these are the Runner, Spanish, Virginia and Valencia. These varieties are characterised by their distinctive nutritional value, flavour and size of kernels. The Runner is a high yielding variety and has evenly shaped and small kernels. Commercially, Runner varieties are used in manufacturing peanut butter. The Virginia has the largest of kernels and is commercially roasted in-shells, processed and sold. The Valencia variety, on the other hand, mostly has three or more kernel per pod and kernels have a bright-red skin.

The Spanish-type is distinguished by its smaller sized kernels, sweet taste and reddish-brown skin. This Spanish variety has higher oil content than the Runner, Virginia and Valencia varieties and are often roasted in the shell and sold (Amber and Katrina, 2004).

Vegetatively, groundnut is grouped into two types: The Runner and the Bunch varieties, Runners have long lateral branches and grow spreading close to the ground. In contrast, the bunch type grows mainly erect and clustered branches (Wright *et al*., 2006).

According to Atuahene-Amankwa *et al*. (1990), improved groundnut varieties have been in Ghana for years. These varieties were released as early as the 1960s, where prominent among the varieties released is Mani Pinter. Subsequently, other improved varieties including, the ICGS 114, Shitaochi (Chinese variety) and the F-mix were released in 1970s, 1985 and 1988 respectively.

2.2 Production of Groundnuts

Asia is the leading producer of groundnuts, accounting for about 63.7% of the world's total production followed by Africa and the Americas with 26% and 10.1% respectively. China tops world's production of groundnuts with over 16 mega tonnes whereas in Africa, Nigeria does by over three (3) mega tonnes.

More than half the world's total production of groundnut goes into oil production and a considerable quantity of groundnut production in developing countries is sold in domestic markets. Groundnuts traded internationally are mostly in three forms: with shells (pods), without shells (kernels) and meal (cake). There is also a large share of this moving trade in groundnut sweets and other candies (Nautiyal, 2002). MoFA (2013) published the gross biological production of legumes for 2012/2013 cropping year as 475,056, 223,253 and 151,709 metric tonnes for groundnuts, cowpea and soya bean respectively. The average yield for 2012 was 1.4 mt/ha with an achievable projection of 2.5 mt/ha representing a 56% increase under effective extension and use of recommended technology. The land area under cultivation from 2007 - 2009 was 343,300 ha and from 2010 - 2012 was 351,700 ha representing a growth rate of 1.21%.

According to Tsigbey (2003), peanut is a major cash crop in Northern Ghana and plays a major role in the diet of the citizens of Ghana. It serves as a major source of vegetable protein and is used extensively in the preparation of many foods. Roasted groundnut in combination with bananas (Kofi broke-man) is a popular snack in Ghana. Groundnut butter is used widely in the preparation of soups among Ghanaian households and also as bread spread. The kernels are pressed for vegetable oil extraction. This activity is a major source of income for rural women. Groundnut cake gotten after the extraction of the oil is also used in the manufacture of indigenous dishes that are rich in proteins. The study again unearthed other additional uses of groundnuts such as hay after plucking of the pods off the plant and either left on the fields or carted home as animal feed. In some localities, groundnut hay serves as an additional source of income to the farmer since the product can be sold in the market (Tsigbey, 2003).

Groundnuts being a legume improves soil fertility through the activity of nitrogen fixation and therefore enhancing the productivity of other crops in the semi-arid cereal cropping systems. Furthermore, little to no inputs is required for cultivating groundnuts, making it suitable for cultivation by smallholding farmers practising low input agriculture (Tsigbey, 2003).

2.3 Harvesting of Groundnut

Harvesting of groundnut has always been laborious and associated with a high level of drudgery to accomplish harvesting tasks.

Determining when to harvest is important. Okello *et al*. (2013) stated that farmers might gain up to 300 - 450 kg/ha of groundnuts and 2 - 3% in standards around the ten (10) day period before desirable harvest. If groundnut is not harvested at its favourable state of maturity, losses greater than 300 - 450 kg/ha could ensue. Regular checking of groundnut is important to determine the harvesting period. Groundnut maturity affects grade, flavour, quality of milling, and storage life. Groundnuts harvested at the exact due date stage, is of premium quality to the producer, aside meeting the required consumer characteristics. During the process of harvesting, extreme caution is required so as not to damage the pods; as such, a situation could ensue in contamination by *Aspergillus parasiticus* or *Aspergillus flavus* culminating in aflatoxin pollution (Okello *et al.*, 2013).

2.4 Groundnut harvesting constraints

Timely harvesting of groundnuts (at crop physiological maturity) affects yield. Harvesting after the physiological maturity date of any groundnut variety results in high pod losses because of the weakening of the pegs as a result of weather changes (Kombiok *et al*., 2012).

The variety of groundnut plant cultivated possess challenges during harvesting. The Runner varieties have been reported to result in high pod losses during harvesting since they grow spreading and form pegs at every node, producing pods. Therefore making it difficult to estimate the right depth and width to harvest while avoiding damage to pods (Kombiok *et al*., 2012).

Groundnut harvesting becomes difficult at low soil moisture content. As the soil moisture content decreases, the soil strength increases and this decreases the digging efficiency resulting in breaking of the pegs of the groundnut pods during harvesting. As this leads to an increase in the percentage of unexposed pod losses (Azmoodeh-Mishamandani *et al*., 2014).

Another constraint to harvesting groundnuts with tractor hitched implements, is determining the right forward speed to achieve optimal performance while reducing losses to the barest minimal. Bako *et al*. (2015) reported that increasing forward speed above 2 km/hr during groundnut harvesting with a tractor-mounted harvester resulted in a decrease of harvesting efficiency while increasing the percentage of damaged pods.

2.5 Groundnut harvesting methods

Okello *et al*. (2013) mentions that there are two major harvesting techniques used in SubSaharan Africa; hand, hoe and animal drawn plough. Whichever method is chosen, care should be taken so as not to damage or lose both pods and seeds.

- **Hand harvesting**

It is ideal for bunch groundnut varieties, established in well-drained, sandy or loamy soils. This method is illustrated in Figure 2.1 and is widely used during the rainy season, when the soil is still loose and moist. Entire brunches of groundnut plant are held and pulled, lifting it out of the soil. It should be emphasised that this is achieved only when the soil is moist enough.

Figure 2.1: Hand harvesting (Source: Okello *et al.*, 2013).

- **Harvesting with a hoe**

Figure 2.2 depicts the harvesting of groundnuts with a hoe. The hoe is used to dig out the plant from the ground, beneath the plant tap-roots

Figure 2.2: Harvesting by hoe (Source: Okello *et al.*, 2013).

- **Animal-drawn groundnut harvesters**

An animal drawn plough is ideal for spreading groundnut varieties established on heavy and dry soil conditions. Some widely used models are shown in Figure 2.3. The practice is achieved by lifting whole crop from the soil and limiting pod loss as much as possible. Digging with a blade should be well beneath the root zone of the crop to minimize damage to pods.

Figure 2.3: Animal-drawn groundnut harvesters (Source: Nautiyal, 2002)

Tractor-drawn harvesters

Several machines are available for harvesting groundnuts. The choice of machine depends on many factors such as varieties grown, land features, local climatic condition, proximity to drying installations and storage buildings, etc. Depending on the machine, groundnuts can be harvested by doing either one operation at a time or several of lifting, shaking and threshing operations simultaneously. Thus, there are lifters, lifter-shakers, and picker-threshers. Harvesting by tractors fitted with lifters is done with a system of frame-mounted blades that cut the soil beneath the taproots and lift up the groundnut plant. Such category of implement is shown in Figure 2.4. Lift-shakers shown in Figures 2.5 and 2.6 have other capabilities in addition to lifting. They uproot the plants and rid them of soil. They also be equipped to lay the plants in windrows (lifter-shaker-windrowers). Indicatively, mechanised pulling and windrowing of the plants requires about 4 - 6 working hours per hectare. Picker-threshers usually finish the work of the above machines by gathering up the windrows for threshing (de Lucia and Assennato, 1994).

Figure 2.4: Tractor-drawn groundnut harvesters (Vagadia *et al*., 2015)

Figure 2.5: Tractor-drawn P.T.O groundnut harvesters (Source: Asghar *et al*., 2014)

Figure 2.6: Tractor-drawn groundnut harvesters (Source: Ademiluyi *et al*., 2012)

2.6 Design of Groundnut Harvesters

Mechanisation of groundnut harvesting is categorised according to the level of human involvement in the harvesting operation. Negrete (2015) discussed semi-mechanised and mechanised methods. The semi- mechanised is when digging, windrowing is completed with the use of an implement while the picking and shelling is done by hand or the reverse. Negrete

(2015) wrote that mechanised harvesting involves a complete performance of the harvesting operation in either two harvesting operations or a combination of the harvesting operations. Thus, one implement digs and the other does the shelling or both processes are done by a combine harvesting machine.

According to the implement design, groundnut harvesting machines are categorised into digger, digger cum shaker, digger cum shaker cum windrowing and lastly combine harvesters (Ademiluyi *et al.,* 2004 and Negrete, 2015).

2.6.1 Design of diggers

According to Ademiluyi *et al*. (2004), groundnut harvesting machinery design depends on the physical effect of digging and shaking. Several machines developed over time have to work and operate on such principles. They either dig only or dig and shake.

Ademiluyi *et al.* (2004) explained that the design concept of the digger comprised a singleplate blade mounted on a frame with the help of two shanks and has a shaker made of fingerlike projections supported by two wheels, each mounted on the rear of the frame. Other design concepts comprise of a digging blade, shaker rods to lift and shake off soil from plants and finally place them inverted together in a row (the process of windrowing).

Zaied *et al.* (2014) developed a self-propelled groundnut harvester comprising of two spear shaped digging blades with one slightly longer than the other. Pandmanathan *et al.* (2006) also developed a tractor-mounted groundnut combine harvester. The design consisted of a long blade (100 mm) mounted on a frame, a pick conveyor to pick up the harvested crop, a flight elevator to pick the groundnuts to the required height to feed the thresher and finally the cleaning sieves to separate grains from pods.

Vagadia *et al*. (2015) developed a tractor-drawn digger-shaker which was coupled to the tractor power take-off (P.T.O). It has a long single blade and lifter rods 300 mm long which break off soil during harvesting. The design also was fitted with two front wheels for depth control.

2.6.2 Implement Blade Geometry, Soil failure and Implement Forces

The selection of the tillage implements is determined by the type and degree of soil disturbance, this however is subject to the draught and penetrative forces required for efficient operation. Depth/width ratio (d/w) and rake angle (α) are the two major factors to consider in the selection and development of an agricultural tillage implement (Godwin and O'Dogherty, 2007).

According to Godwin and O'Dogherty (2007), blades of implements are categorised and distinguished based on their depth/width ratio and are outlined as follows:

- Wide blades (tines) have depth/width ratio < 0.5
- Narrow blades or tines (chisels) have depth/width ratio to be 1< d/w < 6
- Very narrow blades or tines (knifes) have depth/width ratio > 6

Soil disturbance

According to Payne (1956), wide and narrow tines tend to fail soil in the pattern shown in Figure 2.7, when the depth/width ratio is less than 6 and the rake angle is less than 90°. As a result of this, upward and forward deformation occurs and the loosened soil assumes a crescent shape. An increase in the depth/width ratio would result in a soil deformation change.

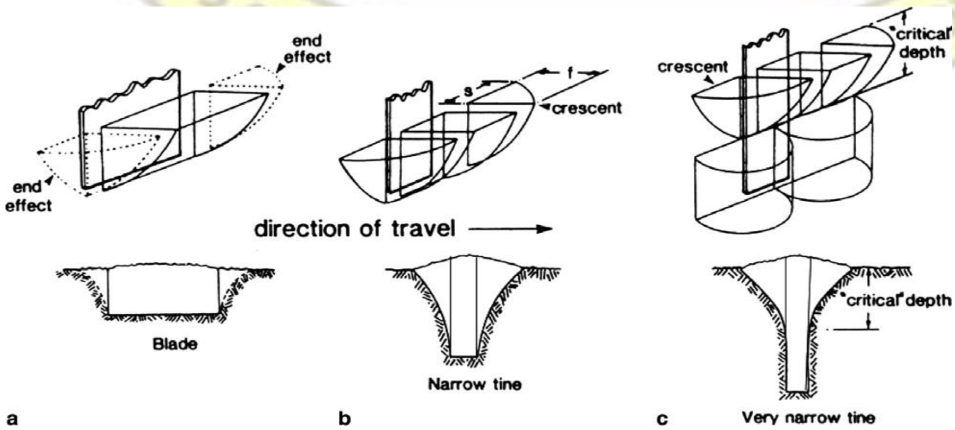

Figure 2.7: Soil Deformation as Affected by Depth/Width Ratio (Source: Smith *et al.*, 1989).

2.6.3 Tines and Effects of Rake Angle

Payne and Tanner (1959) wrote that vertical and horizontal draught forces increase with increasing rake angle (α). It was deduced from data that achieving a lower draught forces and an excellent penetration required that, implements should be designed with lower rake angles.

Godwin *et al.* (1984) showed that the spacing in the multiple tines operating at a common depth does affect the pattern of the soil failure. Implement performance and tine force is significantly affected by the relative positioning of these tines on the implement frame either laterally or in the direction of travel of the implement (Godwin and O'Dogherty, 2007).

Studies by Godwin *et al.* (1984) suggest that, to determine the forces in multiple tines, the individual draught forces for each tine are added together to obtain the equivalent draught force needed to deform the soil area. Figure 2.8 shows soil failure boundaries where there is interaction between and above the tines.

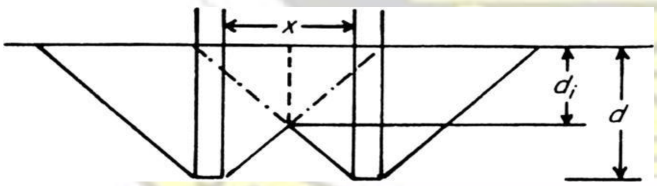

Figure 2.8: A hypothetical soil failure boundary for a group of blades at same depth (Source: Godwin *et al.,* 1984).

2.6.4 Draught force

In wide tines, the prediction of draught forces comes down to the determination of the passive force acting on a blade

P = ($\gamma d^2 N_\gamma + c d N_c + c_a d N_{ca} + q d N_q$) ($w$) □ equation. (2.1) where:

P= Passive draught force (kN) d = depth of blade from horizontal surface (m) w = width of blade (m) c = cohesion (kN/m^2) c_a= soil-interface adhesion (kN/m^2) q = surcharge pressure (kN/m^2) α = rake angle (^{o}) γ = soil bulk density (kN/m^3)

N = dimensionless constant Suffixes for N

γ = gravitational

q = surcharge c_a = adhesion c = cohesion

N_γ, N_c, N_{ca} and N_q which are dimensionless constants depend on the soil friction angle (ϕ) and on the rake angle (α) (Hettiaratchi and Reece, 1974). A range of values of the soil friction angle (ϕ) and the rake angle (α) were graphically obtained from the use of soil-metal friction angle (δ) for δ = 0 and $\delta = \phi$. The dimensionless factor N values are calculated by logarithmic interpolation for soil-metal friction angle, which falls between ϕ and 0 (Hettiaratchi, 1969).

Again, research by Hettiaratchi and Reece (1974) revealed that the soil-metal interface adhesion has an insignificant effect on the passive force P for wide tines, hence the resulting equation:

$P = (\gamma d^2 N_\gamma + cdN_c + qdN_q)\, w$ equation (2.2) where:

P = Passive force (kN) d = depth of blade from horizontal surface (m) w = width of blade (m) c = cohesion (kN/m^2) q = surcharge pressure (kN/m^2) α = rake angle (°) δ = angle of soil-interface friction (°) φ = soil friction angle (°) γ = soil bulk density (kN/m^3)

N = dimensionless constant Suffixes for N

γ = gravitational

q = surcharge c = cohesion

Godwin and O'Dogherty (2006) developed equations to determine the horizontal and vertical draught forces acting on wide tines using quasi-static Mohr-Coulomb soil mechanics making use of passive retaining walls and applying bearing capacity theories. The horizontal and vertical of draught force are as follows:

$H_t = (d\,N^2 \; cdN_c \; qdN_q)\, w \sin$ equation 2.3

$V_t = (d\,N^2 \; cdN_c \; qdN_q)\, w \cos$ equation 2.4 where:

H_t = Horizontal draught force (kN) V_t =

Vertical draught force (kN) d = depth of blade

from horizontal surface (m) w = width of

blade (m) c = cohesion (kN/m^2) q = surcharge

pressure (kN/m^2) α = rake angle (^{o})

δ = angle of soil-interface friction (^{o})

ϕ = soil friction angle (^{o}) γ = soil

bulk density (kN/m^3)

N = dimensionless constant Suffixes

for N

γ = gravitational

q = surcharge c

= cohesion

2.7 Construction of groundnut harvester

The construction of groundnut harvesters is done starting with part list of the working drawings of a design. A part was constructed at a time, mild steel round bars were used for the construction of the frame of a tractor drawn ground digger-shaker (Vagadia *et al*., 2015). According to them, sub-assemblies were held together by bolts and nuts whereas individual parts of a sub-assembly were welded together. The shaker sub-assembly consisted of round shafts, round bars and lifting rods. Lifting rods were welded on shaft at 70 mm spacing and bended downward at the rear end so that a groundnut plant after digging slides backward easily.

Ademiluyi *et al*. (2012) used angle bars, round bars and cylindrical pipes for the construction of a digger/shaker groundnut harvester. Their design comprised two sub-assemblies, the digger and the shaker sub-assemblies. Steel wheels were fitted to a cylindrical pipe with hubs and bearings to enable the forward rotation of two opposite facing rakes welded 90º to the cylindrical pipe during harvesting to lift plant and shake off soil.

Asghar *et al*. (2014) developed and fabricated a groundnut digger by dividing the design into four sub-assemblies consisting of cutting blade, front roller, conveyor and supporting bars. The cutting blade was constructed without notches to improve the slicing of the soil, whereas round bars used for the supporting bars gave the entire digger assembly stability.

2.8 Tractor-mounted groundnut harvester

Tractor-mounted harvesters are the type of harvesters which have their three-point attachment hitched to a tractor. Mooney (1956) designed and patented a tractor-mounted groundnut harvester as far back as the 1950s, capable of being mounted and unmounted on conventional tractors and had adjustable depth and width of harvest. The design comprises a cutting blade and vibrating separating fingers. Apart from the three-point attachment the harvester also makes use of the tractor take-off transmission drive to agitate the separating fingers.

Bako *et al*. (2015) evaluated the performance of a tractor-mounted groundnut harvester, their harvester had an overall dimension of 2050 x 2100 x 1150 mm and a weight of 300 kg. The soil working blade of the harvester was dimensioned 50 x 100 x 150 mm made of mild steel and the blade fixed to the frame at rake angle (α) of 15º. The harvester is capable of harvesting two hectares per day.

Vagadia *et al*. (2015) developed a tractor-mounted groundnut digger-shaker which required power transmission from the power take-off drive. The implement features were a frame, digging blade and a shaker attachment. Their harvester is a fully mounted harvester with two front wheels for depth control.

2.8.1 Three-point Hitch System

The ASABE Standards (2006) seek to guide implement and tractor designers to adhere to recommended standards during designing to achieve optimal performance. Table 2.1 provides standard and certified dimensions for hitch frame design for agricultural implements.

Table 2.1: Hitching Categories and Power Ranges

Description	Category of hitch	ISO 730-1	ASAE S217.11
Specified implement dimension (mm)			

Mast height of Implement	1	460+/-1.5	457
(Clause 0)	2	610+/-1.5	483
	3	685+/-1.5	559
	4L	685+/-1.5	686
	4H	1,100+/-1.5	Not Available
Special hitch categories	1N	400	Not Available
(Clause 0.7)	2N	683	Not Available
	3N	825	822.5–825.5
	4N	920	919–922
Specified tractor power (kW)			
Power range (Clause 0.5)	1	610	559
	2	650	610
	3	735	660
	4L	760	762
	4H	900	Not Available

Source: ASABE (2006).

The degree of variation between the recommended dimensions permits designers to satisfy both ISO and ASAE standards, by adopting minimum ISO dimensions. This would guarantee backward compatibility of modern tractors with already existing implement. From Figure 2.9, the mast height, which is the vertical distance between the upper hitch point and the same axis of the lower hitch points, has specific power requirements for a particular category of hitch.

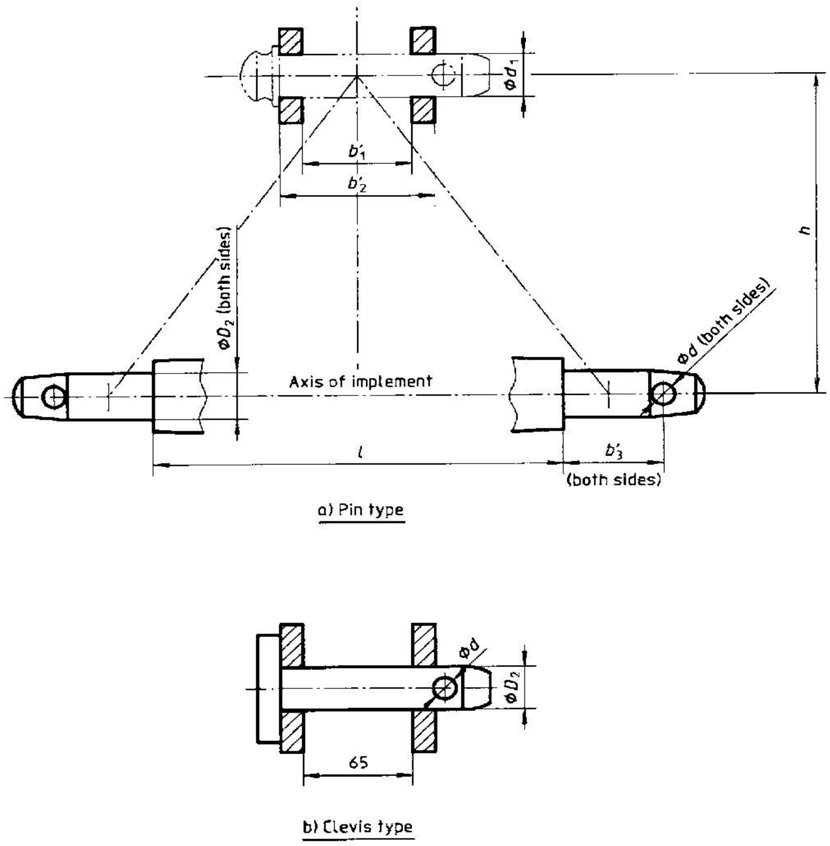

Figure 2.9: Diagrams of Hitch Attachments (Source: ASABE, 2006).

The clevis type applies only to Category 2, 3 and 4.

Table 2.2 specifies dimensions for the hitch attachment and gives the recommended hitch pin holes' diameter and the spacing between the inner faces of the yoke. ASABE (2006) states that it may be necessary to vary these dimensions in case of specialized implements. Where a shorter distance between the lower hitch points appears necessary, the following values are preferred: 400 mm for category 1, 683 mm for category 2, 825 mm for category 3 and 920 mm for category 4. Additional mast heights may be provided for specialized implements and frame-type three-point hitch couplers as given by other standards (e.g. 483 mm for category 2 and 559 mm for category 3 as given by SAE J 715). These additional mast heights shall be within a range of +200 mm from the standard mast height given in the table.

Table 2.2: Specification of Implement Hitch Attachment

Dimension Description		1 (mm)	2 (mm)	3 (mm)
Upper hitch				
ϕd_1	Diameter of hitch pin hole $b_1{}'$	19.3/19.5	25.7/25.9	32/32.5
	Width between inner faces of yoke $b_2{}'$	44.5 min 69 max.	52 min.	52 min
	Width between outer faces of yoke		86 max.	95 max.
Lower hitch ϕD_2	Diameter of hitch pin $b_3{}'$ hitch pin hole distance	21.8/22	27.8/28	36.4/36.6
		39 min.	49 min.	52 min.
l	Lower hitch point span	683±1.5	825± 1.5	965±1.5
Hitch pin hole				
Φd	Diameter for hitch pin hole for upper hitch pin	12 min.	12 min.	12 min
	for lower hitch pins	12 min.	12 min.	17 min
h	Mast height	460±1.5	610± 1.5	685±1.5

(Source: ASABE, 2006.)

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2.7 Evaluation of Groundnut Harvesters

Different methods have been used by researchers to evaluate the performance of agricultural implements. The Indian test codes for evaluating animal drawn groundnut harvester (Indian standard, 1985) have been adapted by many researchers in developing criteria for performance evaluation.

Ademiluyi *et al*. (2004) evaluated the performance of a tractor-drawn digger cum shaker against a tractor-drawn digger. Parameters used in testing the performance of groundnut harvesting machinery were field efficiency, digging efficiency, percentage pod damage, percentage undug pod loss and percentage of unexposed pod loss. obtained these variables by taking into account; the total quantity of pods collected from the plants in the sampled area, the quantity of clean pods collected from the plants dug in the sampled area, the quantity of exposed pods lying on the surface together with the buried pods and lastly the quantity of pods remaining un-detached from the undug plants in the sampled area. Digging efficiency was 39.73% and field efficiency was 60.16% (Ademiluyi *et al*., 2004).

Zaied *et al.* (2014) evaluated the performance of a powered groundnut harvester. A t- test was employed to determine the field efficiency, the effective field capacity and fuel consumption of the harvester on clayey-sand soil and sandy soils. Their research showed the harvester performed better in the clayey-sand soils.

Pandmanathan *et al.* (2006) conducted a performance evaluation on a tractor operated groundnut harvester. The response variables of the research were percentage broken pods, harvest efficiency, cleaning efficiency and threshing efficiency. Harvesting efficiency was 92.3% and the broken pods 4.43%.

Azmoodeh-Mishamandani *et al.* (2014) measured and compared the harvesting losses of manual and mechanised harvesting of groundnuts by using a t-test design. The percentage pod loss, percentage pod damaged, percentage of detached but buried in the soil and the percentage of pods detached but laying exposed on the soil. Their results showed, all the response variables except percentage pod undug to be statistically significance at a confidence level of 99%.

CHAPTER THREE

MATERIALS AND METHODS

This chapter presents the detailed procedure followed to realise the objectives of this study. Figure 3.1 show the individual stages of the processes leading to the design and evaluation of a tractor-mounted groundnut harvester.

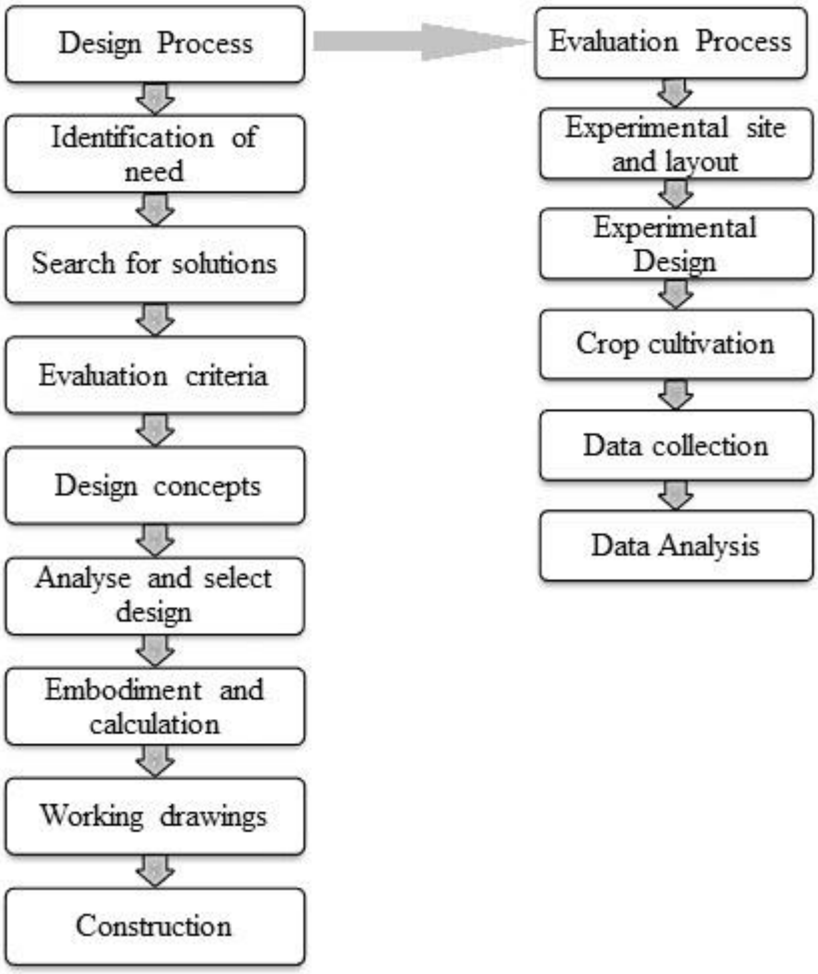


Figure 3.1: Design process and evaluation flow chart

3.1 The Design process

3.1.1 Identification of need

To have a cost effective and a simplified harvester which can reduce drudgery and losses due to hardened soil.

3.1.2 Design problem

Hardening of the soil makes it difficult to uproot groundnuts. Working of the soil, either by watering or use of an implement is therefore required before uprooting of groundnuts. Harvesting under such conditions result in pod yield losses.

3.1.3 Main purpose of the design

This design should cut open the soil beneath the root zone of the groundnut plant, exposing groundnut pods and the plant for further processing. Figure 3.2 illustrates the relationships between the inputs (groundnut crop) of the tractor-mounted groundnut harvester giving an output of the groundnut leaves and pods exposed for further processing.

Figure 3.2: Input and output relationship of the groundnut harvester

Tractor-mounted harvesters achieve the process of harvesting groundnut by either performing one or a combination of lifting, shaking and threshing operation(s) combinations at the same time (de Lucia and Assennato, 1994).

3.1.4 Functional Synthesis

The overall function (harvest groundnuts) was broken down into sub functions fulfilling the main function. The relationship between the specific tasks of cutting open the soil and breaking off soil from the groundnuts was clearly mapped out as shown in Figure 3.3 leading to the realization of overall function of groundnut harvesting.

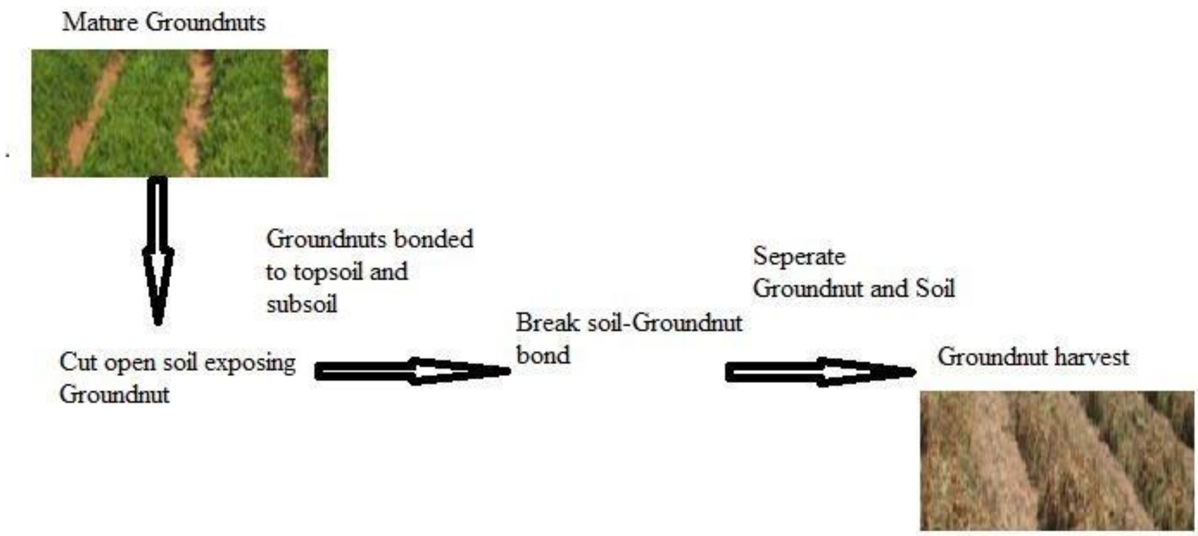


Figure 3.3: Functional structure of Groundnut Harvester.

3.1.5 Solution principles and constraints

Technical solution principle variants were identified in a morphological matrix to ensure the realization of the identified functions. Tillage depth/tool width ratio was crucial to the selection of the tillage implement to achieve soil deformation (Godwin and O'Dogherty, 2007). Since the interest of the solution was to achieve cutting and lifting but not inversion, tine tillage tool variants were opted for. From Figure 3.4 wide tines were selected as the working components of the groundnut harvester on the basis of the width of a ridge (60 cm).

Similarly, three variants of the solution principles were chosen for achieving the dislodging and breaking off the soil attached to the groundnut crop. These variants identified were fixed alternating spikes, rotating spikes and lastly a shaker plate either of which could resolve the dislodging and breaking of the soil. Fixed alternating spikes were selected out of the three since the other two required the power take-off system of a tractor to achieve the desired results. The shaded solution principles show a possible combination that could be arrived at if any of the variants are combined to perform the task.

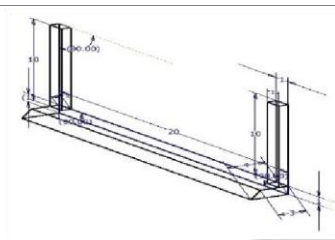
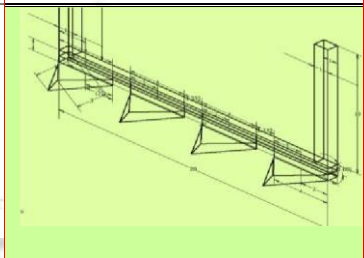
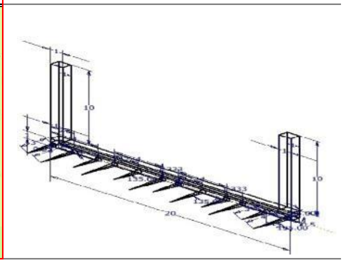
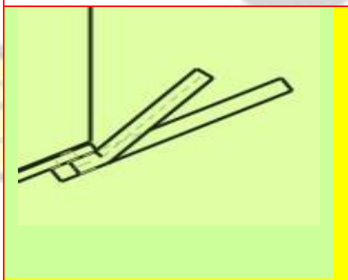
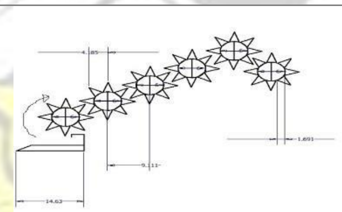
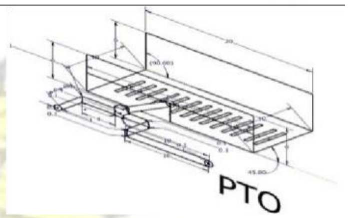
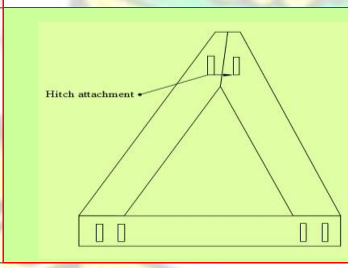
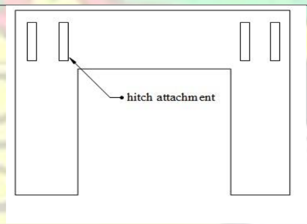
	Solution Principle		
Sub-Function	1. single broad tine	2 group of wide tines	3 narrow tines
1 Cutting			
2 Dislodging and separation	1.altenating spikes	2. rotating spikes	3. plate shaker
			
3 Hitching Frame	1. Fully mounted Aframe	2. Semi-mounted N-frame	
			

Figure 3.4: Morphological Matrix

3.1.6 Evaluation criteria

The criteria for selecting the design of a groundnut harvester were established and built out of the problem confronted. The criteria to successfully designing a tractor-mounted groundnut harvester were:

1. Ease of fabrication (T)
2. Marketability (R)
3. Cost (C)
4. Locally available material (O)
5. Power (P)
6. Safety (S)
7. Ease of servicing (E)
8. Ease of operation (L)
9. Durability (D)
10. Weight (W)

A pairwise ranking was conducted, comparing one criteria with the other, prioritising by choosing the most preferred of the two criteria as illustrated in Appendix 4.

The score for each criteria was expressed as a percentage of the total score. The design criteria with the highest scores were deemed the most important. The first six with the highest score were used as the evaluation criteria.

1. Ease of servicing (E): = 22%
2. Cost (C): = 21%
3. Safety (S): = 16%
4. Ease of fabrication (T): = 16%
5. Ease of operation (L): = 14%

6. Locally available material (O): = 11%

3.1.7 Design concepts

Four alternative solutions to solve the design problem are illustrated by Figure 3.5. The proposed design ideas were:

1. A tractor-mounted groundnut harvester
2. A tractor semi-mounted groundnut harvester
3. A tractor semi-mounted groundnut harvester cum shaker
4. A tractor-mounted groundnut harvester cum windrower

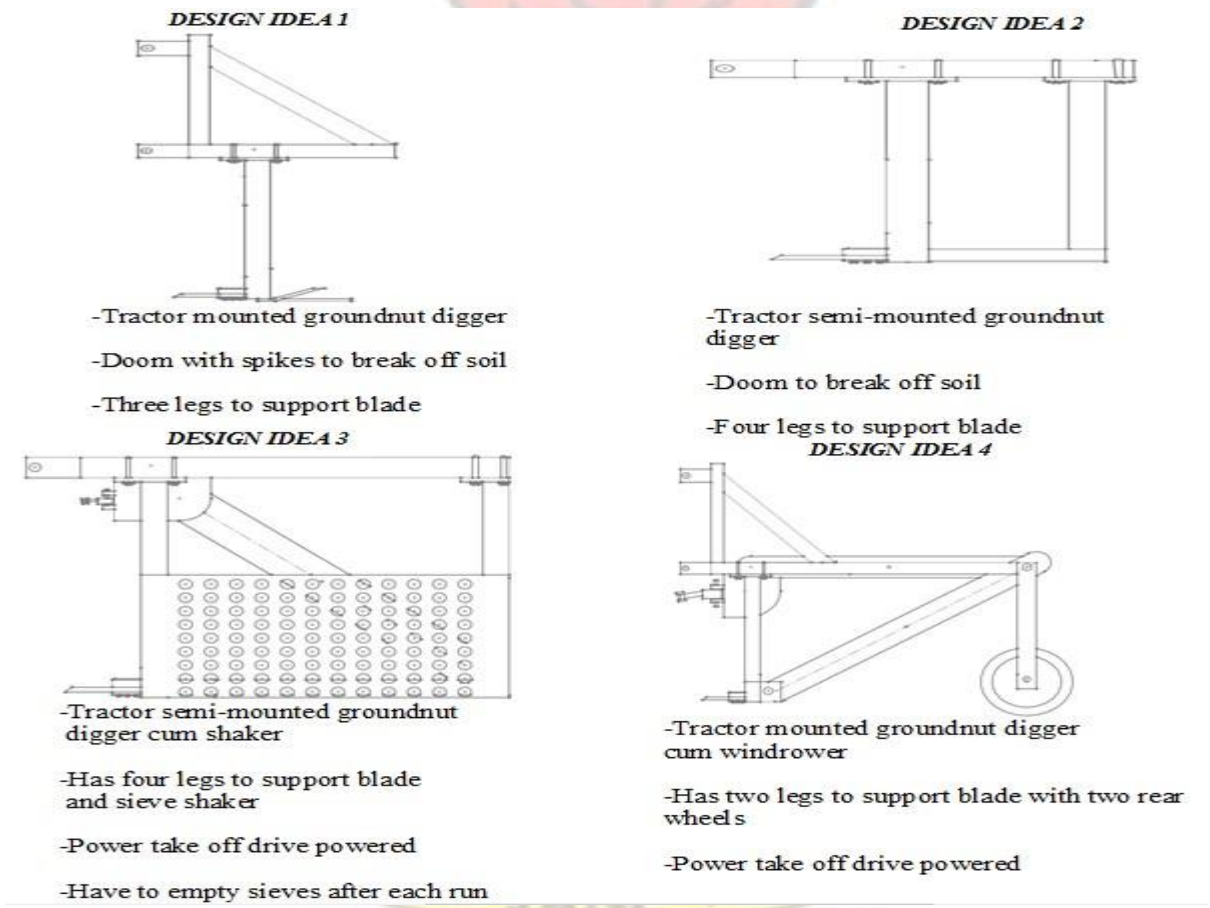


Figure 3.5: Alternative design ideas

The four alternative designs were evaluated using the criteria of ease of servicing, cost, safety, ease of fabrication, ease of operation and local availability of material. For design criteria (ease of servicing), a fully-mounted groundnut harvester was rated excellent; a semimounted harvester was rated fair, while a fully-mounted harvester with a power take-off drive was rated good.

For criteria of locally available material, each alternative design was rated fair since all of the alternative have component parts that can be obtained in Ghana.

Using criteria of cost of manufacturing to rate the designs, fewer parts and processes to accomplish harvesting suggested lower cost, therefore the design with the least number of parts was rate excellent, while the design idea with the most parts were rated poor.

Rating the design ideas with criteria of safety, alternative design that did not require many assemblies were rated good whereas those that required more assemblies were rated bad.

The design ideas that required the power take-off drive were considered cumbersome to operate than those that did not require the power take-off drives, therefore rating based on the criteria of ease of operation scored design ideas requiring power take-off good whereas the other design ideas scored fair.

For the criteria of ease of fabrication, how simple the design idea was and its ease of hitching, were the basis for rating design ideas one (1) and two (2) excellent, design idea three (3) was rated poor and design idea four (4) was rated fair.

The result of the decision matrix is illustrated in Table 3.1. The scale for which the Rating factor (R) were assigned as indicated in Table 3.1 was as follows: Excellent (scored 9-10), Good (scored 8-7), Fair (scored 6-5), Poor (scored 3-4) and Bad (scored 0-2). Assigning a score for any of the ratings was discretionary.

Design idea one (1) had the best total score (791) among the four alternative design and on that basis was chosen as the best design alternative. Furthermore, design idea one (1) obtained the best score (22%) when the evaluation and rating process was done using the most important design criteria (ease of servicing). A tractor-mounted groundnut harvester would be able to harvest groundnut under hard soil conditions, easy to fabricate and operate, as well as being cost effective of the alternatives.

Table 3.1: Decision matrix

		Design							
		1		2		3		4	
Criteria	Weight (W)%	Rating (R)	R x W	R	R x W	R	R x W	R	R x W
Ease of servicing	22	9	198	5	110	5	110	7	154
locally available material	11	9	99	9	99	4	44	6	66
Cost	21	6	126	6	126	6	126	6	126
Safety	16	9	144	8	128	4	64	3	48
Ease of operation	14	8	112	7	98	5	70	6	84
Ease of fabrication	16	7	112	7	112	2	32	2	32
Total	100		791		673		446		510
Rank			1		2		4		3
Continue?			Yes		No		No		No

3.1.8 Embodiment Design

The tractor-mounted groundnut harvester design was broken down into two sub-assemblies namely the hitch frame sub-assembly and the harvesting sub-assembly (the legs and the harvesting blades), see Appendix 7 for part list. Figure 3.6 shows a sketched diagram of the groundnut harvester. The digger was designed to satisfy two rows, whereas that of the dislodging and separation of the soil, alternating spikes at varying angle of attachment to the direction of travel of the blade. Other members of the design include U-bolts, bolts and nuts, spikes, blade hoist, harvester legs and blades.

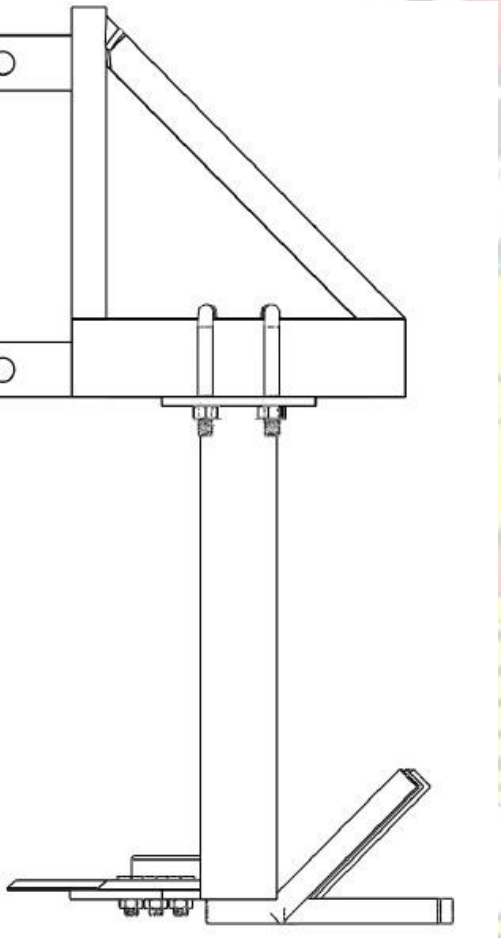


Figure 3.6: Side view of the sketched harvester

3.1.9 Design Calculations

The following calculations were considered in light of designing the tractor-mounted groundnut harvester. The depth of cut and the width of the working tool is crucial to predicting the required draught force. Godwin and O'Dogherty (2007) categorised the blades of implements and distinguished them based on their tillage depth/tool width ratio. Their categorisation was essential to selecting an appropriate draught prediction equation.

Semi-erect and spreading varieties of groundnuts generally spread on the ground at width 20 to 60 cm on either sides of the plant at 8 to 10 cm depth respectively (Vagadia *et al.,* 2015). Therefore, working tool depth 10 cm and a tillage tool width of 60 cm per row (A two-row tractor-mounted harvester). The resulting depth/width ratio was 0.16, which corresponds to Godwin and O'Dogherty (2007) categorisation of wide blades (tines), have depth/width ratio < 0.5. Therefore, the wide tine equation was used to predict the Horizontal draught force of the groundnut harvester.

$$H = (\gamma d^2 N_\gamma + c d N_c + q d N_q)\, w_t \sin(\alpha + \delta) \quad \text{equation (3.1)}$$

For the purpose of this research, it was assumed that, the cut soil glides smoothly over the working implement and so surcharge (q) was taken to be zero.

For the determination of the dimensionless constants, Equation 3.2 together with Reece's catalogues of charts shown in appendix 3. were used.

$$N = N_{0} \left(\frac{N}{N_{0}} \right) \quad \text{equation (3.2)}$$

Where:

N = dimensionless constant
Suffixes for N δ = angle of soil-

interface friction (°) ϕ = soil friction

angle (°)

The values for bulk unit weight (γ) and soil cohesion (c) for sandy loam soils recommended by the American Society of Agricultural and Biological Engineers, are shown in Table 3.2. Table 3.2: Parameters for predicting draught force

Description	**Value**
Bulk unit weight of soil (γ)	15 kNm^{-3}
Soil cohesion (c)	10 kNm^{-2}
Surcharge (q)	0 kNm_{-2}
Angle of soil-metal interface (δ)	20°
Tool rake angle (α)	30°
Angle of internal soil friction (ϕ)	35°

The interpolated values of $N_{\delta=0}$ and $N_{\delta=\phi}$ and the computed dimensionless constants using Equation 3.2 are shown in Table 3.3.

Table 3.3: Interpolated values of $N_{\delta=0}$ and $N_{\delta=\phi}$

	$N_{\delta=0}$	$N_{\delta=\phi}$	Computed N-value
Gravitational ($N\gamma$)	1.20	2.00	1.61
Cohesion (Nc)	0.53	2.80	1.37
Surcharge (Nq)	2.20	4.00	3.10

The stresses and strains were determined and the required dimensions of the components parts of the groundnut harvester were obtained using Equations 3.2 to 3.6. The comparison between the allowable shear moment and the actual (maximum) moment, determines whether the part is safe in bending when a load is applied. It is safe to use a part of chosen dimension when the actual shear moment is less than the allowable shear moment. The size of the bolts and nuts required to optimize the space and give the right fastening of the parts were also determined.

$$\tau = \frac{VQ}{Ib} \quad \text{Equation (3.2)}$$

$$\sigma_{allowable} = \sigma_y / n \quad \text{Equation (3.3)}$$

$$L = L_o\left(1 + \frac{\sigma}{E}\right) \quad \text{Equation (3.4)}$$

$$M_{allowable} = \frac{\sigma_{allowable} \times I}{Y} \quad \text{Equation (3.5)}$$

$$\text{if } I_x = \frac{bh^3}{12} \quad \text{Equation (3.6)}$$

Results obtained from Equations 3.7 to 3.9 were used together with Ajax fasteners catalogues to select the required bolts and nuts for fastening the parts together.

$$\text{tensile area } (A)_t = \frac{F}{f_t} \quad \text{Equation (3.7)}$$

$$\text{shear area } (A)_s = \frac{F}{f_s} \quad \text{Equation (3.8)}$$

$$A = \frac{\pi d^2}{4} \quad \text{Equation (3.9)}$$

preload force (F) = $f_{S..factor} \times$ shear force $(F)_s$ Equation (3.9)

Where; τ = Shearing

stress

V = shear in the beam at a given point along the beam length, obtained from the shear diagram

Q = $a\bar{y}$ $a\bar{y}$ first moment of area

a = area above or below which the shear stress is desired

$\bar{y}$ = distance from the beam cross section neutral axis to the area above or below the plane where the stress is to be examined

I_o = moment of inertia of the entire beam cross-sectional area b =

width of the beam at the plane where the stress is being examined y =

Distance from the neutral axis to the point the stress is acting

M = Maximum bending moment from diagram

F = Preload force $\sigma_{allowable}$ = Allowable shear

moment A = Cross-sectional area of the bolt n

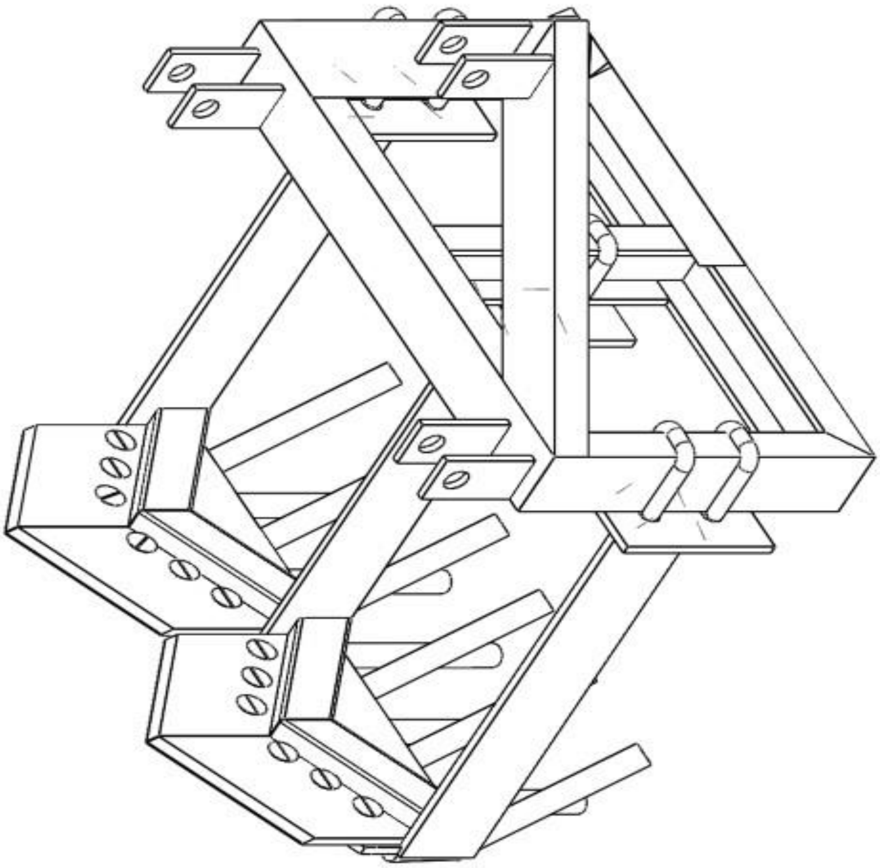
= Safety factor σ_y = Yield strength

L = Design length of material
L_o = Assumed length

E = Modulus of Elasticity

3.1.10 Working drawings

Drawings were made using SOLIDWORKS software version 2015. A 3D (three dimensional) model (Figure 3.7) of the groundnut harvester was first created, modelling each individual part of the harvester at a time. Working drawings (Assembly and detailed drawings) were then created from the 3D model and saved in a portable document format (pdf).



(Isometric view)

Figure 3.7: 3 D model view of designed groundnut harvester

3.1.11. Construction of Groundnut Harvester

Fabrication was done at the Kwame Nkrumah University of Science and Technology. The

Workshop of the Department of Agricultural Engineering and assembled at the Bolgatanga Polytechnic Workshops. Required raw materials for the construction were obtained from the part list. The raw material comprised of c-channels (45 □ 100) mm, flat bars (10□ 100) mm, 16 mm circular bar and a 12 mm plate (1000 □1000) mm.

Blades

The detailed dimensions of the blade was marked out on a cardboard and cut out. The blades were cut from a leaf spring 12 mm thick, with a blow torch and the front edge of the blade milled to an angle of 30º. The bolt holes were drilled with a power drill.

Legs, blade hoist and frame hoist

The legs, blade hoist and frame hoist were cut out from a 12 mm thick mild steel plate. The patterns were first cut out from cardboards using the detailed dimensions before tracing these patterns out on the plate and then cut out pattern with a blow torch. Holes were drilled through the blade hoist corresponding to the holes drilled on the blades to aid easy fastening together with the M12 bolts before welding the legs onto the blade hoist, since the reverse situation would make drilling difficult. The frame hoist plate(s) holes were drilled for M18 U-bolts before welding onto the legs as shown in Figure 3.8.

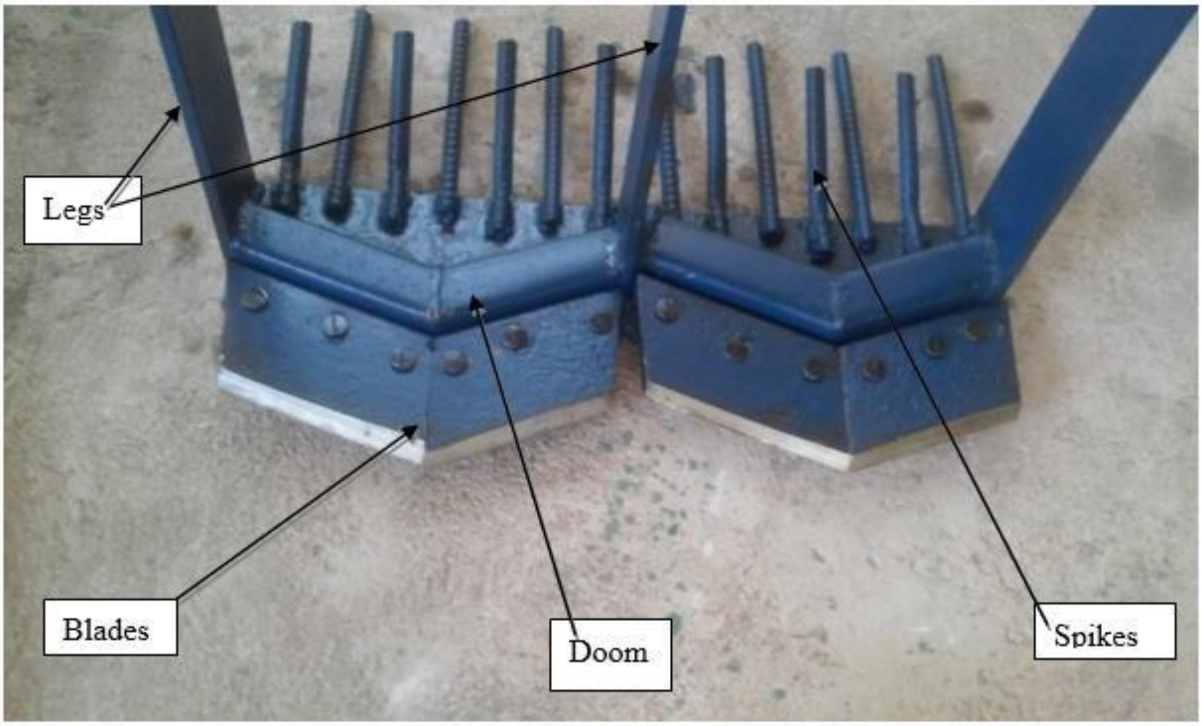


Figure 3.8: Harvester base

The doom and spikes

A 3 mm plate was used for the fabrication of the doom. The dimensions were marked out on the plate with a scriber and cut out with a grinding disc and then bent into the doom shape with a bending machine. The doom was welded onto the blade hoist as detailed by the working drawings. Round bars of 16 mm in diameter were cut to the required dimensioned sizes and then bent at given angles (45º) on a clamp and welded to the rear end of the blade hoist at their appropriate intervals and alternating arrangements.

Hitch frame and attachments

A 45 × 100 mm c-channel bars were used for the fabrication of the frame. A scriber was used to mark out the required dimensions on the bar and cut out with a power saw. The cut out parts were put together in their right orientation as prescribed by the working drawings and welded together. The 3 pairs of hitch attachments were marked out with patterns before using a blow torch to do the cutting. The holes for the hitch pin were drilled with a power drill and the hitch attachment pairs welded in place at their right positions as seen in Figure 3.6.

U-bolts

The U-bolts were made by first marking out the required dimension on a Ø16 mm smooth rod and threaded at both ends. The bars were then heated in a furnace and then bent to shape on an anvil with the aid of a mallet. The heated bars were held with the thong.

Assembling of the harvester was done at Bolgatanga Polytechnic. Figure 3.9 shows the assembled groundnut harvester. The hitch frame sub assembly was fastened firmly in place to the leg sub assembly by the U-bolts, before attaching the blades to the blade hoist with the M 12 bolts. A grinder and sand paper were used to smoothen the rough edges of the groundnut before painting the implement with blue paint.

(a) (b)

Figure 3.9: Front and back views of Groundnut harvester

3.2 Experimental site

The experiments were conducted at Bolgatanga Polytechnic, Sumbrungo in the Upper East Region of Ghana. The field is located on the North western part of the Region, on latitude 10° 49' N and longitude 00° 56' W (GPS map 76csx).The total field area obtained with GPS map 76csx was 3010.50 m^2; the soil type is sandy loam.

3.3 Experimental design

The experiment used was a Randomized Complete Block Design (RCBD), comprising five (5) treatments and three (3) replications.

The five treatments were as follows:

1. H_0 = hand pulling
2. H_1 = hand fork
3. H_2 = hoe
4. H_3 = cutlass
5. H_4 = groundnut harvester

Hand pulling is the widely used mode of harvesting in Northern Ghana and so was selected as the control method of harvesting. There were fifteen (15) plots on the field with five treatments per block. The field was prepared into plots, measuring 4 m × 6 m and ridges ploughed on the plots. Ten (10) m spacing was allowed between blocks and 10 m between plots to allow for free movement of the tractor. The recommended plant spacing and seed rate were 50 × 20 cm and one seed per hole as shown in Appendix 9.

The estimated plant population density per plot was 240 plants and 3,600 groundnut plants per the entire field. A diesel engine tractor, Agria 885 Thinker, with a horsepower of 57 (43 kW) was used for the study and operated at a travelling speed of 5 km/h.

3.4 Agronomic and Cultural Practices

The field for the experiment was ploughed with a disc plough and harrowed with a tine harrow after five days to get an even working soil tilth. A mouldboard ridger was used to make ridges along the length of the field before dividing the field into plots.

The planting material was obtained from the Savannah Agricultural Research Institute, the early maturing and semi-erect Chinese variety (Shitaochi) of groundnuts was used. The seeds obtained were subjected to a simple seed viability test, where the one hundred (100) seeds were selected from the 10 kg of seeds purchased and planted at depth 4 cm on a ridge. The number of seedlings germinated were counted after the seventh day and expressed as a percentage of the total seeds planted (100 seeds: 97% germination rate).

Planting was done on the 30th of June 2015, planting one (1) seed per hole at a depth of 4 cm. A line and pegs were used to mark out the plant distance (50 × 20 cm) on the ridges. A hoe was used for planting.

Refilling of holes that had no seed emerging at all on the seventh day to meet the requirement of one seed per hole.

Weed control

Weeding was done 14 days after sowing, with a hand hoe. Weeding was again done by hand pulling, 29 days after planting.

Harvesting

Harvesting of the groundnuts was done on the 30th September, 2015 with a tractor mounted groundnut harvester, a hand hoe, hand fork, hand pulling and a cutlass on their treatment plots as indicated on the plot layout in Appendix 9.

3.5 Data collection

3.5.1 Characteristics of field soil

Composite soil samples were collected with a gouge auger at depth ranges of 0 - 30 cm. A total of 20 samples were randomly taken across the area of the field and sent to the Savannah Agricultural Research Institute (SARI) for analysis. Table 3.4 shows the physical and chemical properties of the soil.

Table 3.4: Physical and chemical properties of soil

Parameter	Value
pH (1:1.5 H_2O)	6.86
Organic Carbon (%)	0.527
Nitrogen (%)	0.0483
Phosphorus (mg/kg)	7.89
Potassium (mg/kg)	114.29
Calcium (mg/kg)	146.87
Magnesium (mg/kg)	93.64
Cation exchange capacity (cmol/kg)	18.05
Percentage sand	70.0
Percentage silt	24.4
Percentage clay	5.6
Texture	Sandy loam

(Source: SARI, 2015.)

3.5.2 Vine and Pod yield

At harvest, a block was harvested at a time beginning with block (1) one. Trained data collection staff were positioned on each of the treatment plots in a block at the same time, with stop watches each.

The harvesting staff comprised; a tractor operator and eleven other staff. Every treatment in a block was assigned two staff each (one data collection staff and one harvesting staff). The harvesting staff were asked to start harvesting at the same time. This was repeated for each of the remaining blocks and the harvest collected into sacks. The harvest was taken to the laboratory, sorted into polythene bags and weighed.

The vine and pod yield of the groundnuts yield was obtained with a spring scale. Equation 3.12 was used to compute the vine and pod yield.

$$\text{Vine and Pod yield (kg/ha)} = \frac{\text{weight of vine and pod yield (kg)}}{\text{Area harvested (ha)}} \quad \text{Equation (3.10)}$$

3.5.3 1000-Seed Weight

The groundnuts were sun dried to a moisture content of about 8% (monitoring moisture of samples daily with a digital moisture meter) before cracking the pods to obtain the seed, the 1000 seed weight was measured in grams (g) with a precision scale and the average for five samples of each of the harvest of all the 15 replications recorded.

3.5.4 Percentage Pod Yield Losses

The percentage pod loss was determined by assessing plant material over a 24 m^2 area of individual treatments. This was done with guidance from the Indian Standards Test Codes for evaluating groundnut harvester; Animal drawn (Indian Standards, 1985). The groundnuts harvested were collected into polythene bags according to their respective Blocks and treatments. Damaged and detached pods on the field were also collected into polythene bags according to treatment. The harvest was sent to the farm house where the groundnut pods were plucked from the plants. The vegetative foliage was separated and bagged differently from the pods.

The plucked groundnut pods were sorted (damaged pods and whole pods) and bagged according to treatment and by block after which they were weighed. The percentages of the pods and vines were computed as a percentage of the total quantity of harvest for each treatment.

Plant material obtained from the test plots were sorted as follows:

a) ***Total Damaged pods***: these were obtained by collecting all the harvested plants, plucking all the matured pods and hand picking out the damaged pods.

b) ***Total Exposed detached pods:*** these were obtained by going round the crop row collecting the detached pods (per treatment) lying exposed on the soil surface.

c) ***Total Unexposed detached pods:*** these were the detached pods buried in the soil and were obtained by manually digging the entire treatment plot with the aid of a hoe.

d) ***Total Undug pods:*** these were the pods from the plants that remained undug after the harvesting operation.

The following relations were used for the determination of the pod

losses: $A = B + C$ □ Equation (3.11) where

A = Total quantity of pods collected from harvested plants in the plot area

B = Quantity of clean pods collected from the plants dug in the plot area; exposed pods lying on the surface and the buried pods

C = Quantity of damaged pods collected from the plants in the plot area

D = Quantity of detached pods lying exposed on the surface

E = Quantity of detached pods that remained buried in the soil of the sample area

F = Quantity of pods that remained un-detached from the undug plants in the sample area

Percentage of damaged pods loss $= \frac{C}{A} \times 100\,\%$ Equation (3.12)

Percentage of exposed pod loss $= \frac{D}{A} \times 100\,\%$ Equation (3.13)

Percentage of unexposed pod loss $= \frac{E}{A} \times 100\,\%$ Equation (3.14)

Percentage of undug pod loss $= \frac{F}{A} \times 100\,\%$ Equation (3.15)

Total percentage of pod loss = percentage of exposed pod loss + percentage of unexposed pod loss + percentage of undug pod loss + percentage of damaged pods.

3.6 Data Analysis

Data collected were statistically analysed using MINITAB (version 17) to run a Balanced Analysis of Variance (Balanced ANOVA) to test for significance at 95% confidence level and determine the effect of harvesting method on pod and vine yield, pod yield losses and 1000-grain weight of the harvest. The least significant difference (LSD) was computed to differentiate between treatment means where significant difference was observed.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

The aim of the study was to design, construct and evaluate the performance of a tractormounted groundnut harvester. This chapter presents and discusses the results gathered, presenting design specifications, diagrams and pictures of the groundnut harvester. The chapter also presents the results on the evaluation of the performance of the groundnut harvester in comparison with hand hoe, hand fork, cutlass and hand pulling methods of harvesting groundnuts.

4.2 Design and construction of a Groundnut harvester

The design and construction of the groundnut harvesting equipment was done at the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology. Table 4.1 shows a summary of the results from calculations on the design specifications.

Table 4.1: Design specifications

Specifications of a Groundnut Harvesting Machine	Issued date: 7^{th} June 2014.
Parameter	Specification
Prime mover	Tractor-mounted
Row	Two row harvester 1.0
Draught force	kN
Cost of production	≤ Gh₵5000.00
Material	Mild steel
Weight	≤ 150 kg
Overall dimensions	1200 x 630 x 1600 mm

Figure 4.1 shows the trimetric view of a tractor-mounted groundnut harvester while Figure 4.2 shows a picture of the constructed tractor-mounted groundnut harvester. Appendices 7 and 9

show pictures of the tractor-mounted harvester and the detailed production drawing respectively.

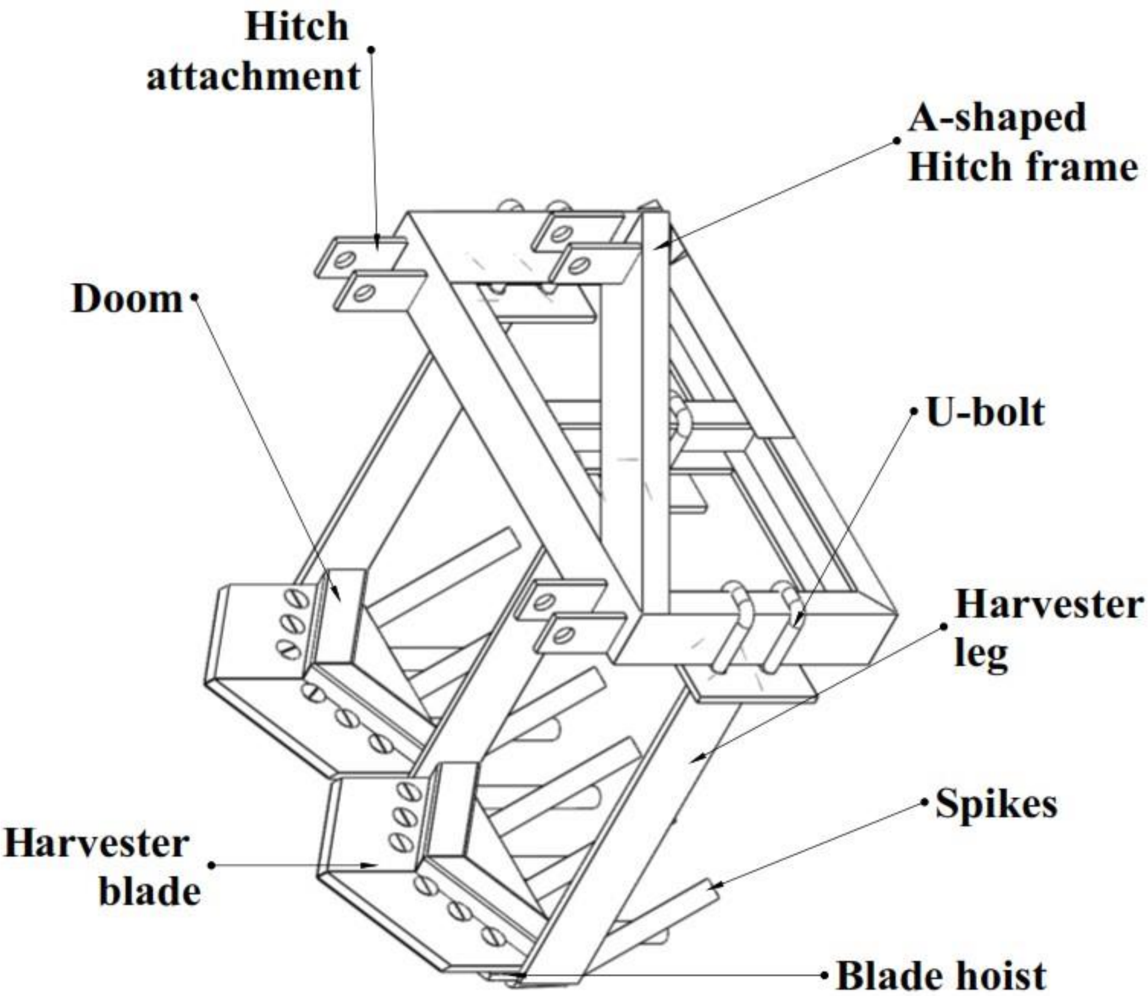


Figure 4.1: Designed tractor mounted groundnut harvester

Figure 4.2: Hitched Harvester

4.3 Comparison of yield (pods and vines) with harvesting method

Figure 4.3 shows the mean pods and vine yield of the individual harvesting methods. Analyses of variance showed that there was no significant difference ($p > 0.05$) between the treatment means of vine and pod yield. Hand pulling (the control method), recorded the highest vine and pod yield of 4708 kg/ha, followed by yield of hand hoe with 4042 kg/ha, yield of hand fork with 2403 kg/ha, yield of groundnut harvester with 1833 kg/ha and harvesting with a cutlass recorded the smallest vine and pod yield of 1861 kg/ha.

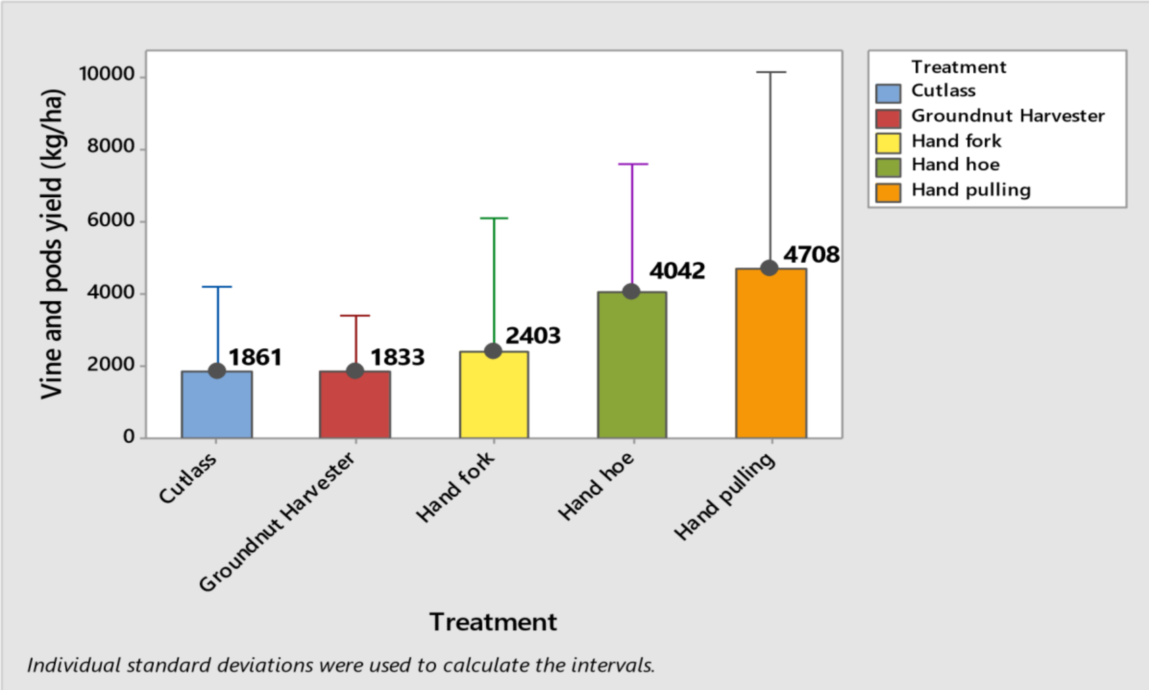


Figure 4.3: Mean vine and pod yield

4.4 Percentage damaged pods (%)

There was statistically significant difference ($p < 0.05$) between the treatment means of the percentage of damaged pods. This indicated that the percentage of damaged pods of one or more of the methods was significantly higher than, the other. It also meant that the percentage damaged pods was affected by the harvesting method used. The cutlass, recorded the highest percentage of damaged pods of 0.44%, followed by the groundnut harvester with 0.19%, which is also followed by hand hoe with 0.11%. Hand pulling and hand fork harvesting methods recorded no damages. The control method of harvesting (hand pulling) had no damaged pods compared with the groundnut harvester, however, the groundnut harvester damaged relatively less pods compared with the cutlass, groundnut harvester and Hand fork methods.

Figure 4.4 shows the percentage pod damage as affected by different harvesting methods. There was significantly higher pod damage with the cutlass when harvesting than those of the hand hoe, hand fork and hand pulling methods. The control method of hand pulling, compared with the groundnut harvester was non-significant, depicting that neither the groundnut harvester nor hand pulling had a comparative advantage over the other in terms of damaged groundnut pods.

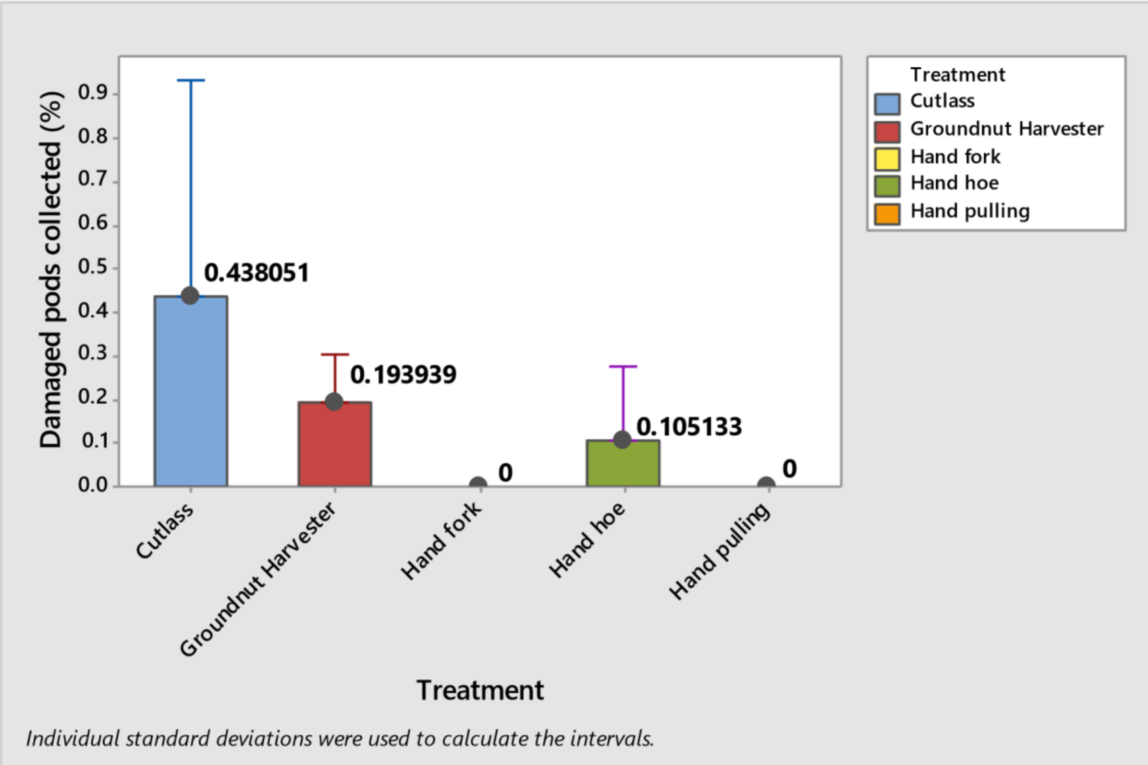


Figure 4.4: Damaged pods (%) as affected by harvesting method

4.5 Percentage Detached pod

The analysis of variance showed a significant difference ($p < 0.05$) in the treatment means of harvesting methods on the percentage of total pods detached from plant during harvesting. The groundnut harvester had a mean percentage of the total pods detached to be 25.45%, followed by cutlass with 2.21%, hand fork 0.55%, hand pulling 0.22% and the hand hoe with the least percentage of total pods detached of 0.00%.

Figure 4.5 shows the mean of percentage detached pods as affected by harvesting method There was significant difference between treatment means of the groundnut harvester and the control method of hand pulling, indicating that the groundnut harvester was significantly higher in percentage of total pods detached during harvesting than the hand pulling method. Furthermore, there was significant difference between the groundnut harvester and the hand hoe, the cutlass and the hand fork methods of harvesting. The differences could be attributed to the huge losses recorded, resulting from both the unexposed detached pod loss and exposed detached pod loss with mean average values of 14.63% and 10.82% respectively for the groundnut harvester. Soil moisture content at harvest has a positive correlation on the percentage of total pods detached at harvest (Ademiluyi *et al*., 2004). The soil moisture content coupled with the speed of harvesting can affect the percentage of losses, since the digging blade could encounter a lot more resistance than expected. Again it was observed during the harvesting operation that the middle leg of the harvester which gave the design more stability, offered some resistance to the free movement of plant debris over the digging blade and so the high likelihood of detached pod losses. Azmoodeh-Mishamadani *et al.* (2014) recorded 75% percentage pod loss to be due to detached pods losses, as against
99.96% of the entire pod loss due to detached pods by this study.

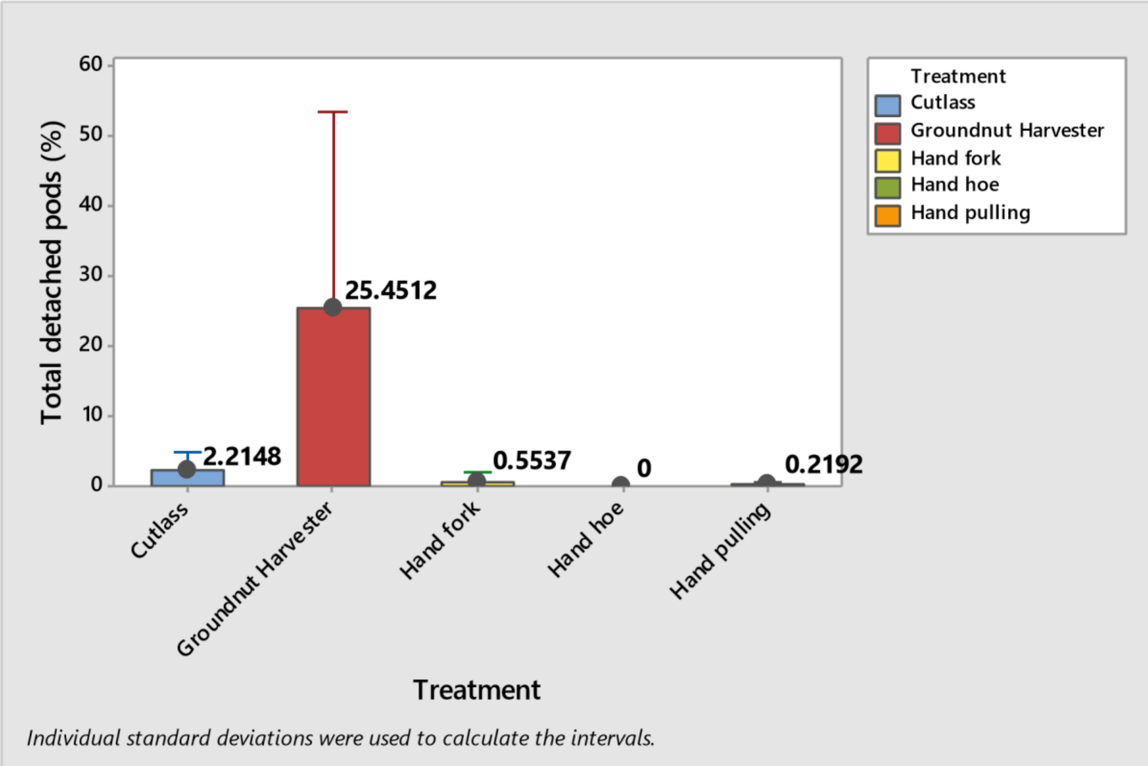


Figure 4.5: Mean Total detached pods (%)

4.6 Effect of harvesting method on pod yield loss (%)

The analysis of variance revealed there was significant difference ($p < 0.05$) between the methods of harvesting. The groundnut harvester had the highest loss of 25.65%, followed by the cutlass (1.28%), hand fork with mean losses of 0.55%.this was followed by hand pulling 0.22% and lastly by hand hoe harvesting with the least harvesting losses encountered of 0.11%.

Figure 4.6 shows the mean values of the percentage pod yield loss obtained from the various harvesting methods. Hand pulling's mean pod loss was significantly different from the groundnut harvester. The groundnut harvester had significantly higher pod yield loss compared with harvesting by hand pulling. Harvesting by cutlass, hand hoe and hand fork are similarly significantly lower in pod losses compared with the groundnut harvester. These findings agree with the results of Azmoodeh-Mishamadani *et al.* (2014) where mechanical harvesting of groundnuts was significantly higher in terms of total pod yield loss than manual harvesting

(20.2% and 3.5% respectively). A greater percentage of the total pod loss (99.96%) was due to the percentage of detached pod loss. The thick foliage of the groundnut made it easy for the clogging of the groundnut harvester offering resistance during harvesting, resulting in losses. The soil moisture content at which the harvesting was done may have made it difficult in harvesting with either of the methods since such conditions make the soil hard and susceptible to cracking. Adelimuyi *et al.* (2004) and Kombiok *et al.* (2012) noticed the soil moisture content at harvest had a positive correlation with the pod losses. Ademiluyi *et al.* (2004) findings showed the least pod losses were obtained at 5.60% moisture content while the highest pod losses obtained at 4.63% soil moisture content.

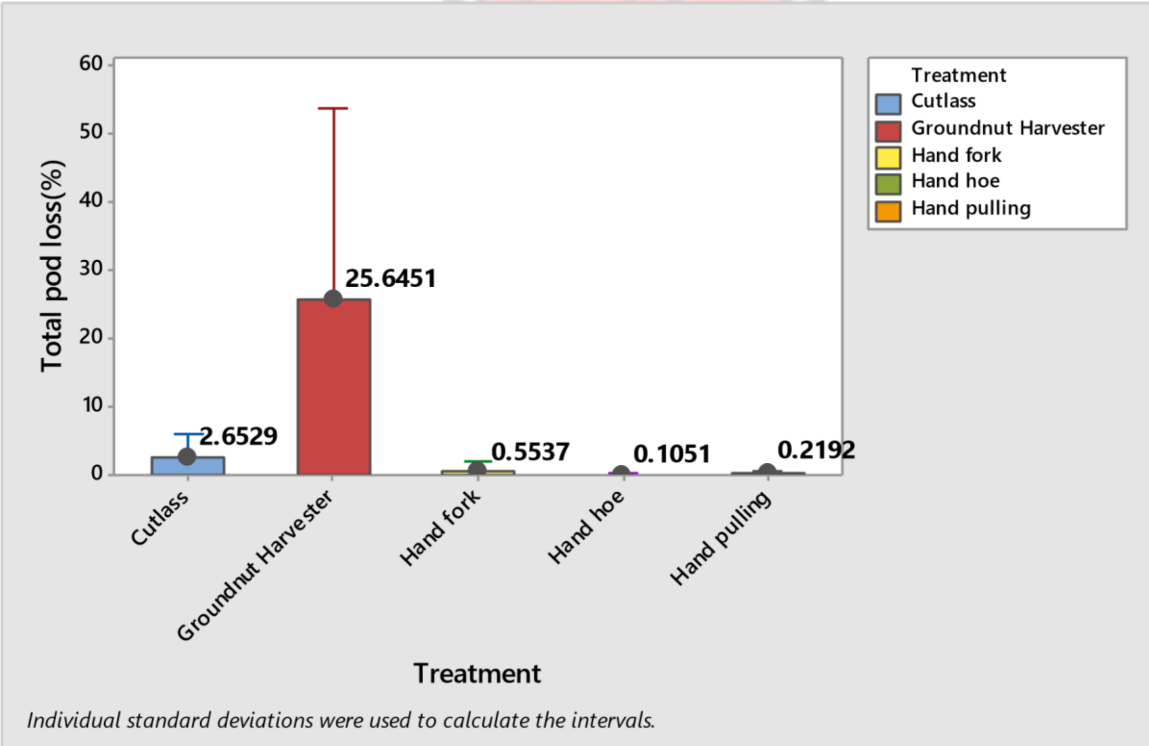


Figure 4.6: Mean Total Percentage Pod yield loss

4.7 1000-seed weight and harvesting methods

Figure 4.7 presents 1000-seed weight of the harvesting methods. Groundnuts 1000-seed harvested with the hand fork had the highest seed weight of 394 g, followed by seed weight of the groundnut harvester 360 g, seed weight of hand hoe harvesting 341 g, seed weight from the control harvesting method (hand pulling) 329 g, and finally the least weight obtained from seeds harvested with a cutlass 299 g. The analysis of variance showed that, there was no significant difference ($p > 0.05$) between the harvesting methods on 1000-seed weight.

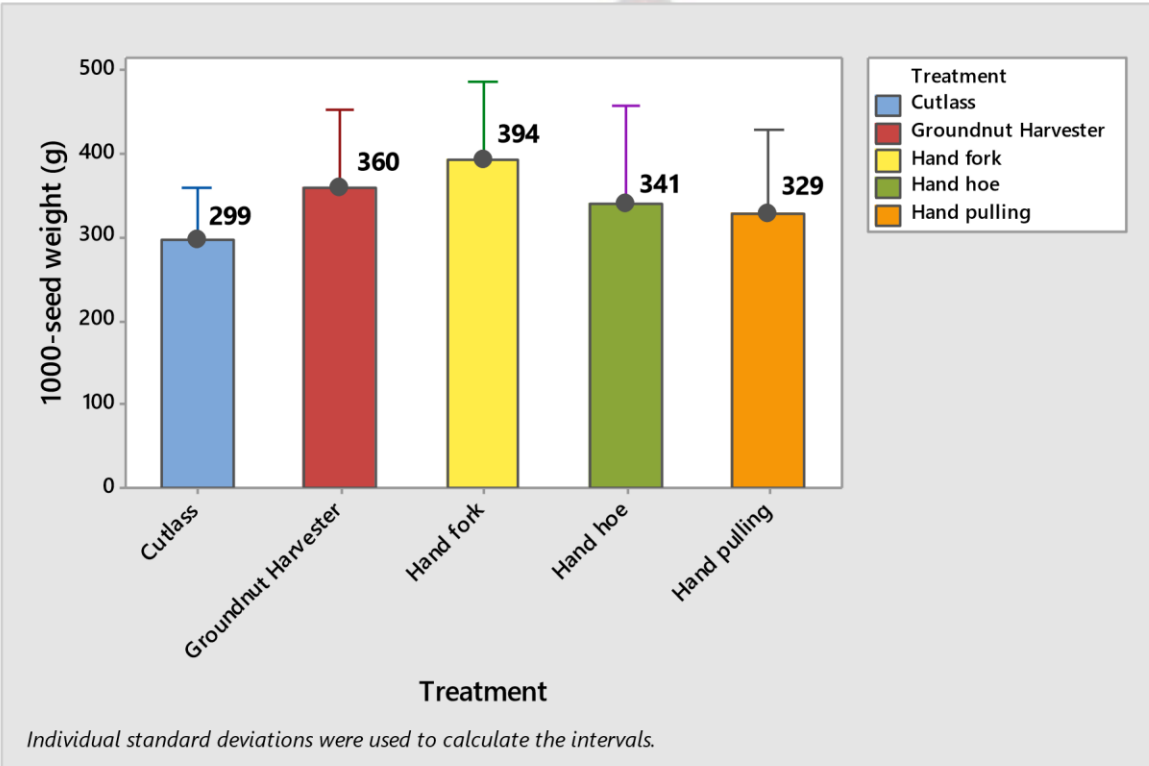


Figure 4.7: Mean 1000-seed weight of harvesting method

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the results and discussion of this research, the following conclusions were drawn:

1. Locally available materials were used for the construction of a groundnut harvester with minimum draught force of 1.0 kN, is tractor-mounted and a two-row harvester. The design is such that, it can be used to harvest groundnut on commercial scale and at low soil moisture content. The tractor-mounted groundnut harvester though with setbacks, fulfils an aspect of groundnut harvesting process, which is digging and is locally manufactured.
2. It was observed that in comparison with the control harvesting method (hand pulling), the groundnut harvester had the least vine and pod yield of 1833 kg/ha, representing a 38.94% reduction of vine and pod yield compared with the hand pulling.
3. The percentage damage of pods is affected by harvesting method. However, between hand pulling method (the control method of harvesting) and groundnut harvester there was no statistically significant difference between their treatment means 0.20% and 0.00% respectively. The percentage of detached pod during a harvest operation is affected by the harvesting method. The groundnut harvester resulted in the most pods detached 25.45% than any other of the method investigated.

   The percentage detached pod losses realized could have been due to factors like clogging and physical properties of the soil like soil moisture content and soil bulk density among others.

   The percentage pod losses of the groundnut harvester were significantly high compared with the other methods of harvesting. The groundnut harvester is no alternative to the traditional method of hand pulling during harvesting in terms of avoiding losses accrued during harvesting. A greater percentage (99.96%) of the total pod losses of the groundnut harvester. is attributed to the detached pod loss.
4. The 1000-grain weight count of the harvesting method revealed that none of the methods of harvesting groundnut investigated by the study is significantly higher than the other. The lack of statistical significance means that 1000-grain weight is not

affected by harvesting method. The groundnut harvester recorded a relatively higher grain weight than hand pulling harvesting.

5.2 Recommendations

The carrying out of this research had its challenges and successes. Therefore, based on the findings the following suggestions were arrived at.

1. It is recommended that, further work be done to equip the groundnut harvester with other processing functions like windrowing and plucking of the groundnut pods.
2. The tractor-mounted groundnut harvester should be evaluated, varying the days of harvesting, so as to know the effect of soil physical properties like moisture content on the performance of the implement.
3. It is further recommended that; this research be conducted cultivating groundnuts on the flat of the soil instead to evaluate the performance of the tractor mounted groundnut harvester.
4. Further work should be done to modify and optimize the design of the tractormounted groundnut harvester to effectively utilize the tractor's working width, reducing clogging which could intern reduce the pod yield losses.

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APPENDICES

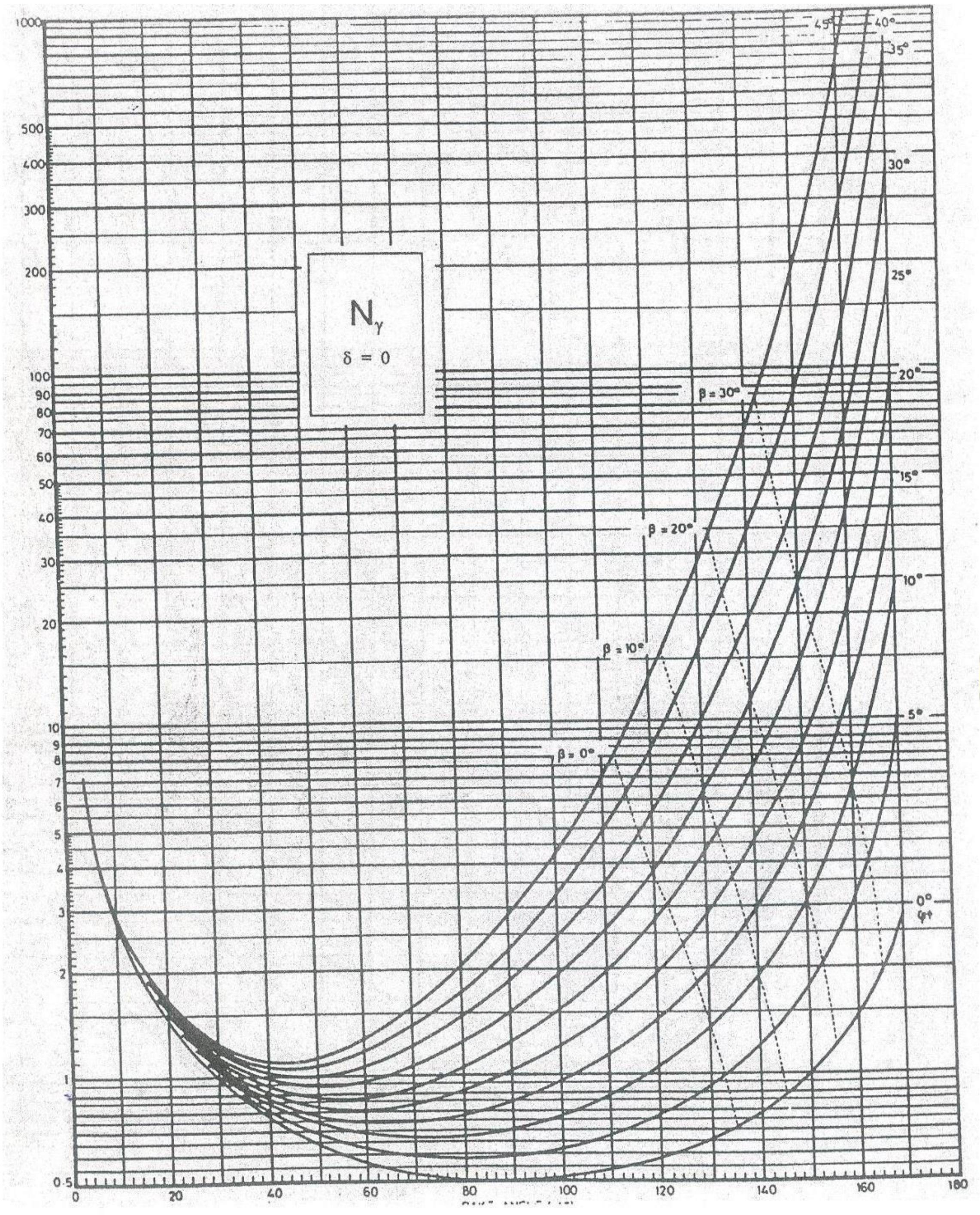
Appendix 1**:** Average values of typical properties of top soils

Table 8. 1: Typical properties of top soils

	Sandy Loam	Loam	Clay Loam
Bulk unit weight (γ)	15 kN/m^3	15 kN/m^3	14 kN/m^3
Cohesion (c)	10 kN/m^2	20 kN/m^2	30 kN/m^2
Angle of internal friction (Φ)	35°	20°	10°
Angle of soil-metal friction (δ)	22°	10°	6°
Adhesion (Ca)	0	0	0

Source: (ASABE typical soil properties, 2013)

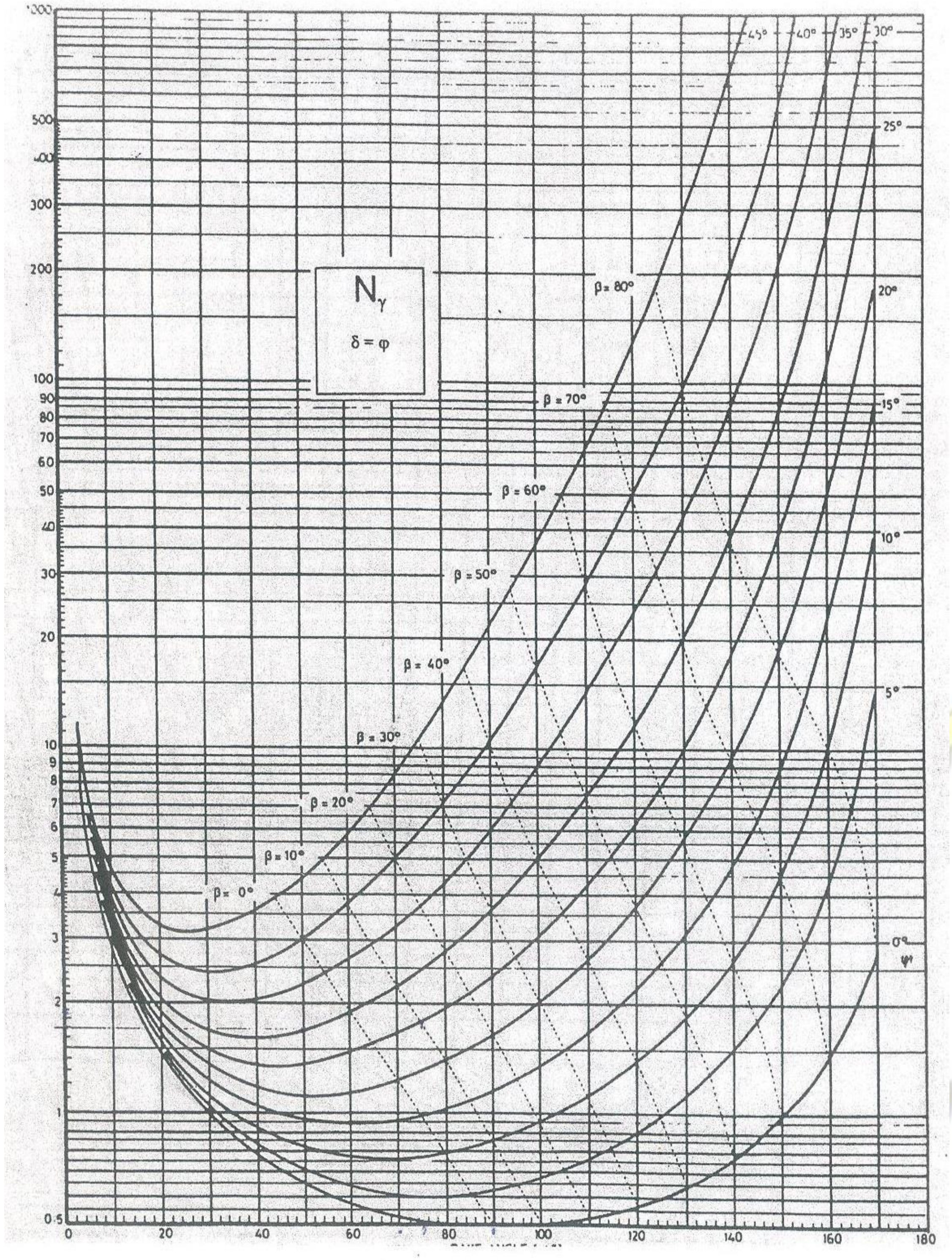
Appendix 2(a): GRAVITATIONAL: Smooth



Rake Angle (α)

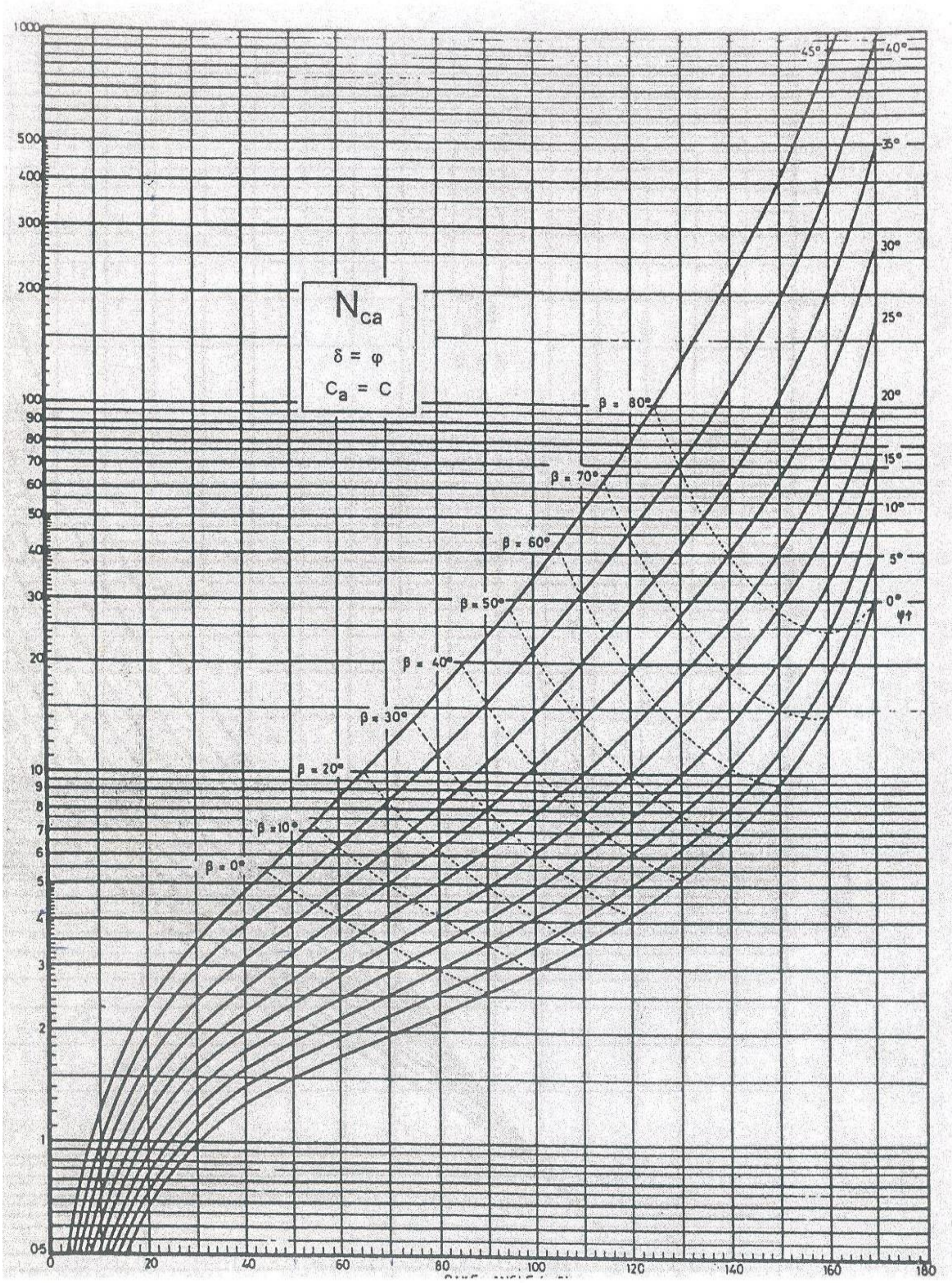
Source: Hettiaratchi and Reece (1974).

Appendix 2(b): GRAVITATIONAL: Rough



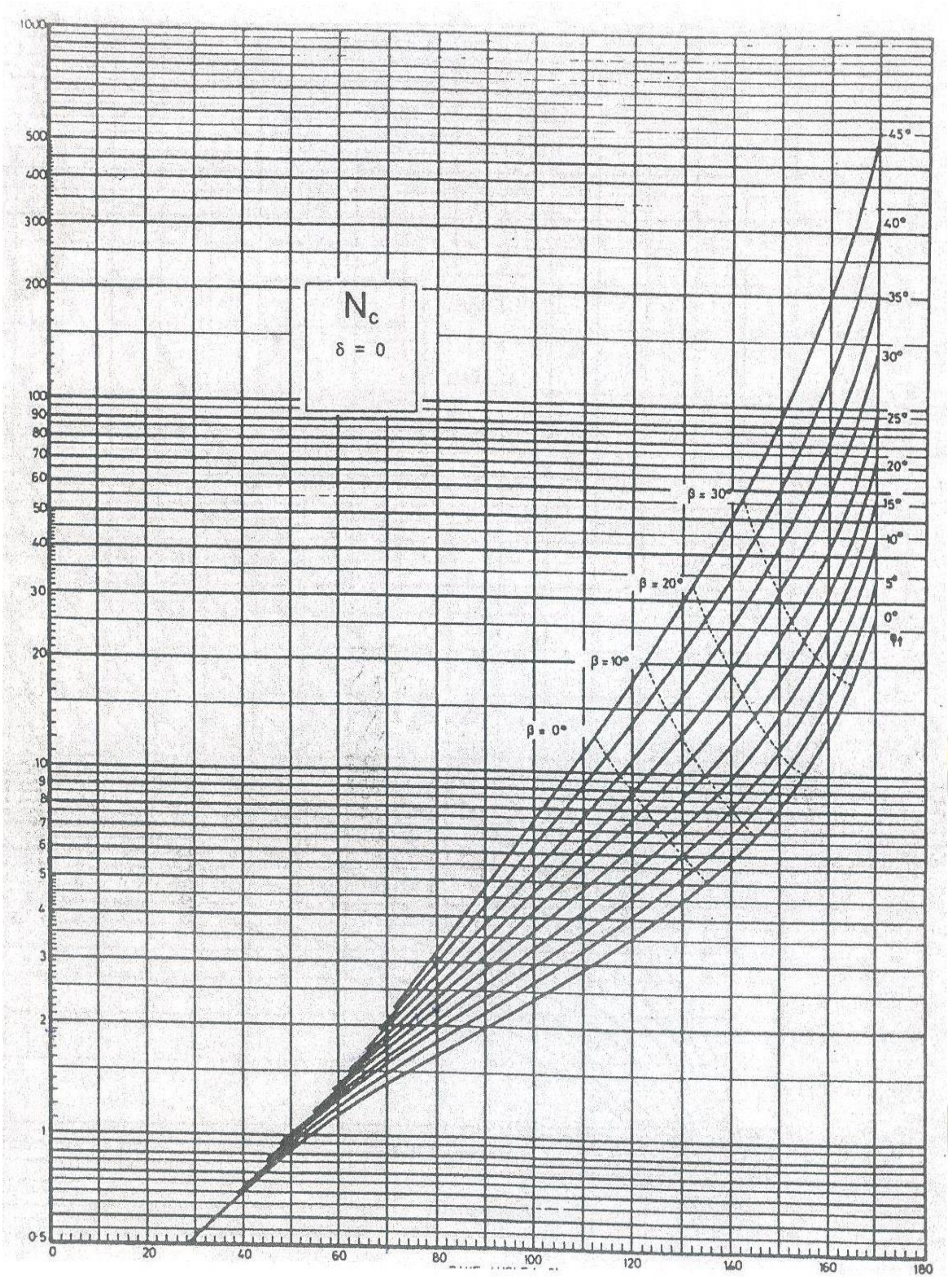
Rake Angle (α)

Source: Hettiaratchi and Reece (1974).
Appendix 2(c): COHESIVE: Rough



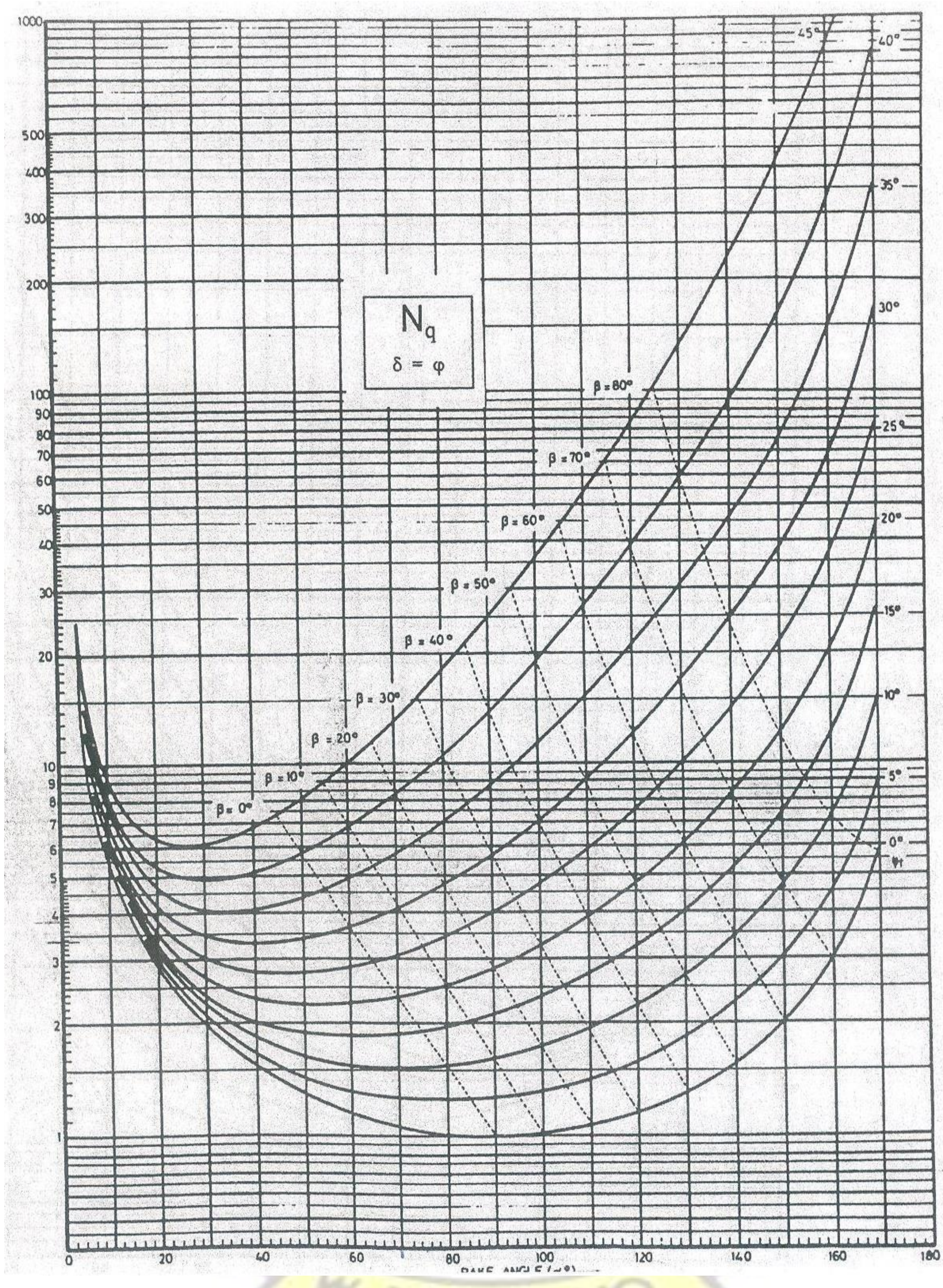
Rake Angle (α)

Source: Hettiaratchi and Reece (1974).
Appendix 2(d): COHESIVE: Smooth



Rake Angle (α)

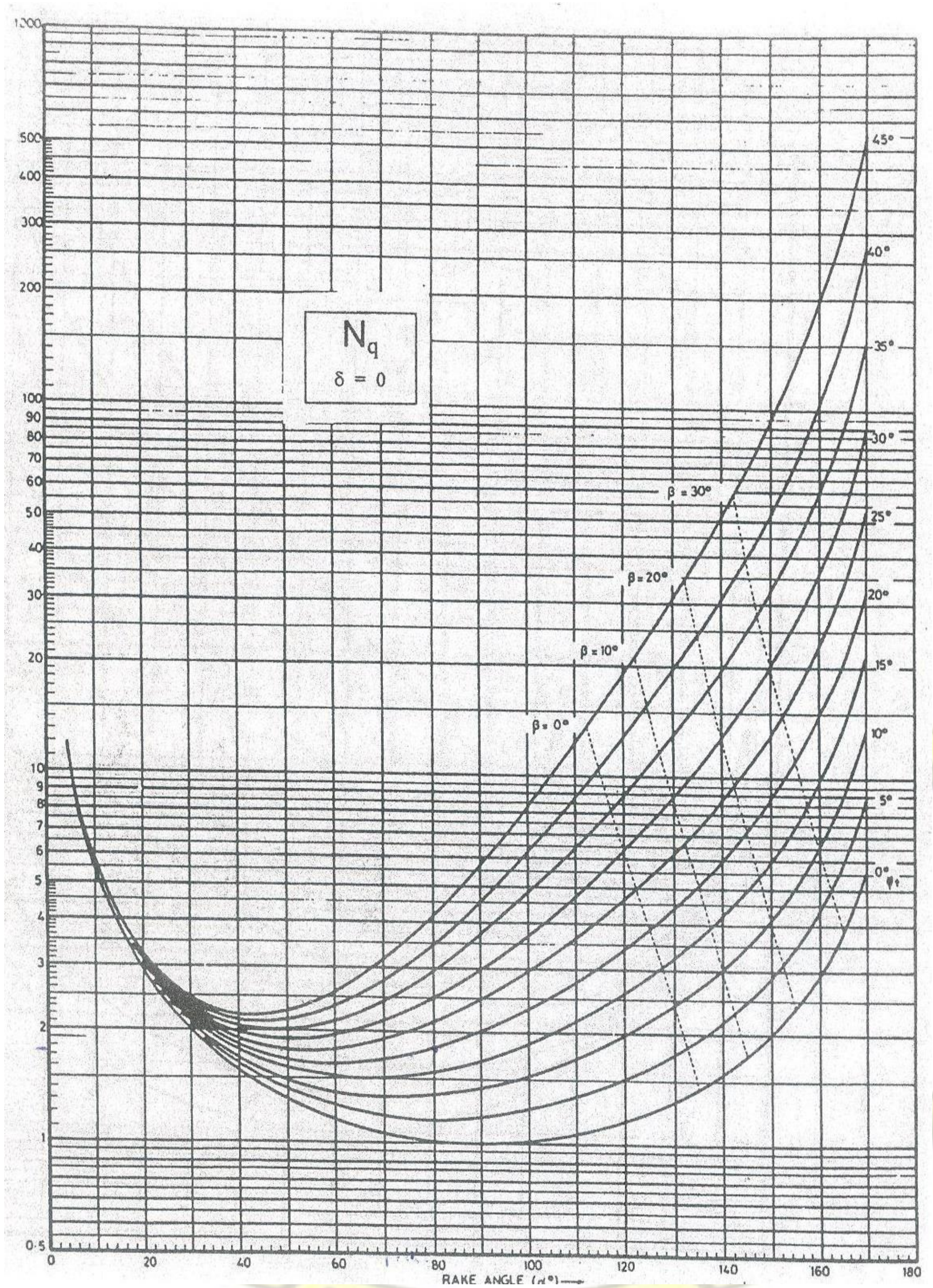
Source: Hettiaratchi and Reece (1974).
Appendix: 2(e) SURCHARGE: Rough



Rake Angle (α)

Source: Hettiaratchi and Reece (1974).

Appendix 2(f): SURCHARGE: smooth



Rake Angle (α)

Source: Hettiaratchi and Reece (1974).

Appendix 3: Evaluation and weighing of selection criteria

Table 8. 2: Criteria selection matrix

Criteria	T	R	L	C	P	S	E	O	D	W	Score	weights
T		T	C	T	T	T	E	O	T	T	6 T’s	13.33
R	-		L	C	P	S	E	C	R	W	1 R	2.22
L	-	-		L	P	L	E	L	D	L	5 L’s	11.11
C	-	-	-		C	C	E	C	C	C	7 C’s	15.55
P	-	-	-	-		S	E	O	P	W	3 P’s	6.66
S	-	-	-	-	-		S	S	S	S	6 S’s	13.33
E	-	-	-	-	-	-		E	E	E	8 E’s	17.77
O	-	-	-	-	-	-	-		O	O	4 O’s	8.88
D	-	-	-	-	-	-	-	-		D	2 D’s	4.44
W	-	-	-	-	-	-	-	-	-		3 W’s	6.66

The score for each criteria was expressed as a percentage of the total score. The design criteria with the highest scores were deemed the most important. The first six with the highest score as highlighted in Table 8.2 above were used as the evaluation criteria. The total score of the six evaluation criteria was determined and each score converted to 100%.

weight □six criteria weights

1. Ease of servicing (E): 18 =____________________□100% = 22%
2. Cost (C): 17 = 21%
3. Safety (S): 13 = 16%
4. Ease of fabrication (T): 13 = 16%
5. Ease of operation (L): 11 = 14%
6. Locally available material (O): 9 = 11%

Appendix 4: Computed N_γ, N_c and N_q values

Value for N when = 0 was found to be = 1.20 from appendix 2 (a)

Value for N when = was found to be = 2.00 from appendix 2 (b)

N = N 0 equation (4.1)

20° / 35°

N = 1.20 1.202.00

N = 1.61

Value for N when = 0 was found to be = 0.53 from appendix 2 (c)
c

Value for N when = was found to be = 2.80 from appendix 2 (d)
c

NC = NC 0 equation (4.2)

20° / 35°

NC = 0.53 2.800.53

N_C = 1.37

Value for N when = 0 was found to be = 2.20 from appendix 2 (e)
q

Value for N_q when δ = 35° was found to be = 4.00 from appendix 2 (f)

$N_q = N_q(0) + \left(\dfrac{N_q(\phi) - N_q(0)}{20^\circ}\right) 35^\circ$ equation (4.3)

N = 2.20 q + (4.00 − 2.20)

N = 3.10 q

$H = t\left[\gamma d^2 N_\gamma + cdN_c + qdN_q\right] w \sin(\alpha + \delta)$

$H_t = [(15)(0.1)(1.61)^2 + (10)(0.1)(1.37) + (0)(0.1)(3.10)](1.2) \sin(30^o + 20)^o$

$H_t = 1.5$ kN

If harvesting operation was at a speed of 5 km/h, then the required horsepower is

$= 1500\ \text{N} \left(\dfrac{5000}{3600}\ \dfrac{\text{m}}{\text{s}}\right) = 2.0\ \text{kW} \approx 2.7\ \text{hp}$

Table 8. 3: Computed horizontal draught force at varying depths

Depth (m)	Horizontal draught force (kN)	Vertical draught force (kN)
0.05	0.685188	0.574941
0.1	1.481377	1.243022
0.15	2.388565	2.004243
0.2	3.406753	2.858605
0.25	4.535941	3.806106
0.3	5.776128	4.846747
0.35	7.127316	5.980528

0.4	8.589503	7.207448
0.45	10.16269	8.527509
0.5	11.84688	9.940710

For the predicted vertical draught force

$$V_t = -\left[\left(\gamma d N_\gamma + c d N_c + q d N_q^2\right) w\right] \cos(\alpha + \delta)$$

$$V_t = -\left[(15)(0.1)(1.61)^2 + (10)(0.1)(1.37) + (0)(0.1)(3.10)\right](1.2) \cos(30^o + 20)^o$$

$V_t = -1.2\ \mathrm{kN}$

Appendix 5.1: Calculations

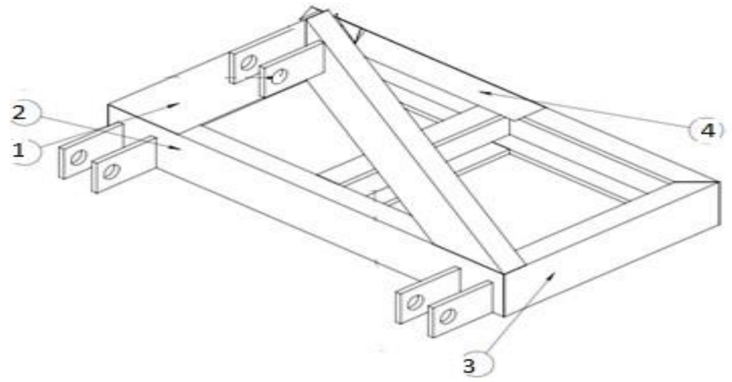


Figure 8. 1: Harvester hitch frame

Table 8. 4: Parameters for determining moment of inertia of the frame

About x-axis						
Segments	a(mm^2)	y(mm)	ay(mm^3)	d(mm)	ad^2(mm^4)	I_o(mm^4)
1	450	62.5	10125	45	911250	3750
2	800	40	32000	0	0	426666.7
3	450	62.5	10125	45	911250	3750
□□	1700		52344		1822500	434166.7

About y-axis segments						
	a(mm^2)	y(mm)	ay(mm^3)	d(mm)	ad^2(mm^4)	I_o(mm^4)
1	450	22.5	9900	0	0	75937.5
2	800	5	4000	0	0	6666.6
3	450	22.5	9900	0	0	75937.5
□□	1700		23800		0	22541.6

$$\bar{y} = \frac{\sum ay}{\sum a} = \frac{52344\,mm^3}{1700\,mm^2} = 30.8\,mm$$

$$I_1 = \frac{b_1 h_1^3}{12} = \frac{45mm(10mm)^3}{12} = 3750\,mm^4$$

$$I_2 = \frac{b_2 h_2^3}{12} = \frac{10mm(80mm)^3}{12} = 426666.7\,mm^4$$

$$I_3 = \frac{b_3 h_3^3}{12} = \frac{45mm(10mm)^3}{12} = 3750\,mm^4$$

$$I_{xx} = \sum I_o + \sum ad^2 = 434166.7 + 1822500 = 2256666.7\,mm^4$$

for moment of inertia about y-axis

$$I_1 = \frac{b_1 h_1^3}{12} = \frac{10mm(45mm)^3}{12} = 75937.5\,mm^4$$

$$I_2 = \frac{b_2 h_2^3}{12} = \frac{80mm(10mm)^3}{12} = 6666.6\,mm^4$$

$$I_3 = \frac{b_3 h_3^3}{12} = \frac{10mm(45mm)^3}{12} = 75937.5\,mm^4$$

$$I_{yy} = \sum I_o + \sum ad^2 = 22541.6 + 0 = 22541.6\,mm^4$$

If the yield strength for steel (σ_y) = 250 MPa

The Modulus of Elasticity (E) = 207 MPa

Then $\sigma_{allowable} = \sigma_y / n$

Where n is safety factor = 3.5

$\sigma_{allowable} = 250/3.5$

$\sigma_{allowable} = 71.43\ N/mm^{-2}$ if

$L = 400\ mm_o$

Therefore using the equation $L = L_o(1+\frac{\sigma}{E})$

$$L = 400\left(1 + \frac{71.43}{207}\right)$$

$= 538$ mm

to obtimize the design 566 mm was selected as the length of the outer leg

Area of the c-channel bar $= (45 \times 10) + (80 \times 10) + (45 \times 10) = 1700\ mm^2$

Stress for section 1 (transverse section), if a force of 31 kN (maximum power from tractor 43 kW at a speed of 5m/s) = 3100 N is applied

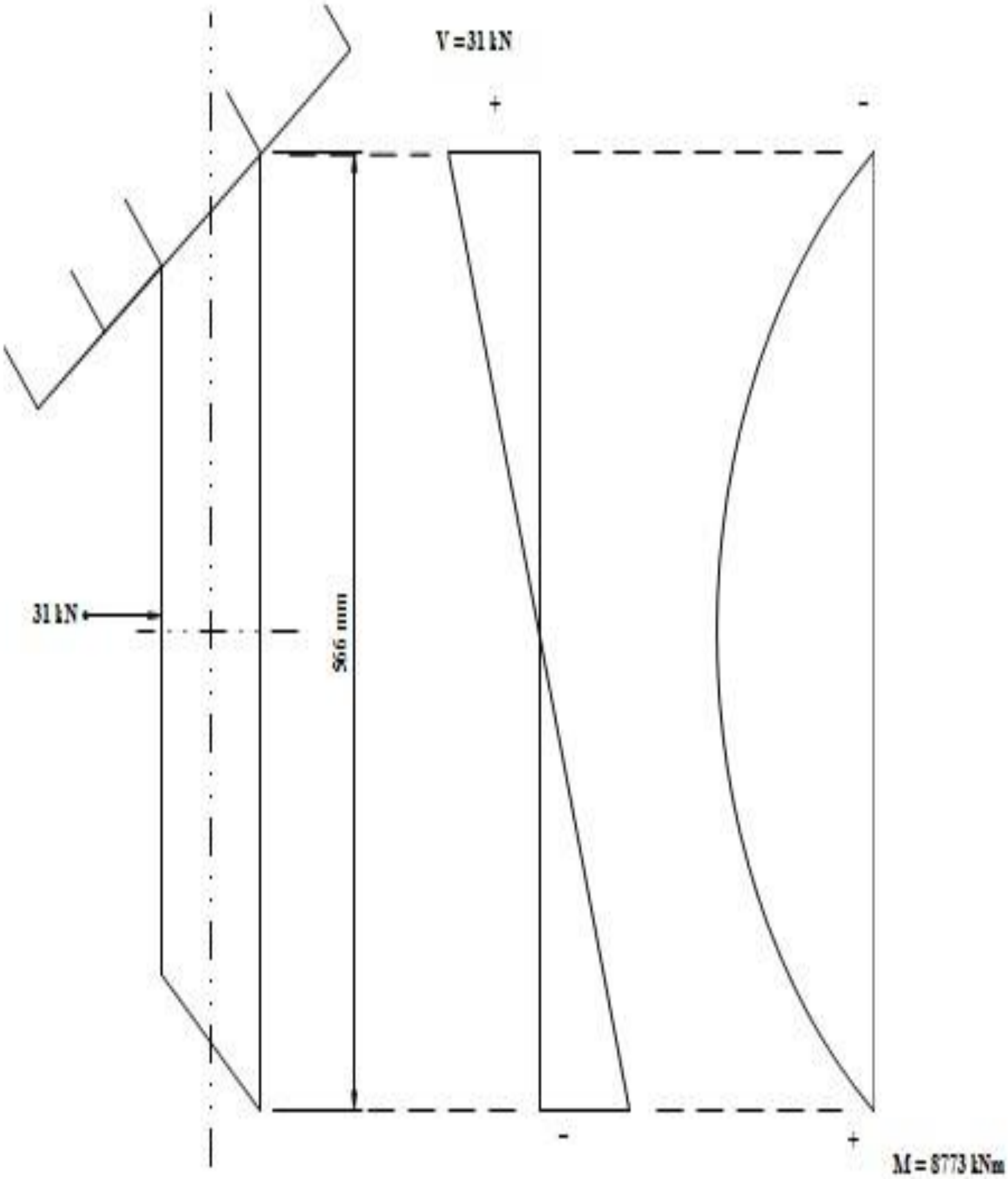


Figure 8. 2: Bending moment and share force diagram for bar (1)

$$M_{allowable} = \frac{\sigma_{allowable} \times I_{XX}}{y} = \frac{(71430\ Nm^{-2} \times 2256666.7mm^4)}{22.5\ mm}$$

$= 716416.5\ kNm$

$M_{allowable} > M_{actual}$ the harvester frame transverse bar is safe for bending

Longitudinal section bar (2)

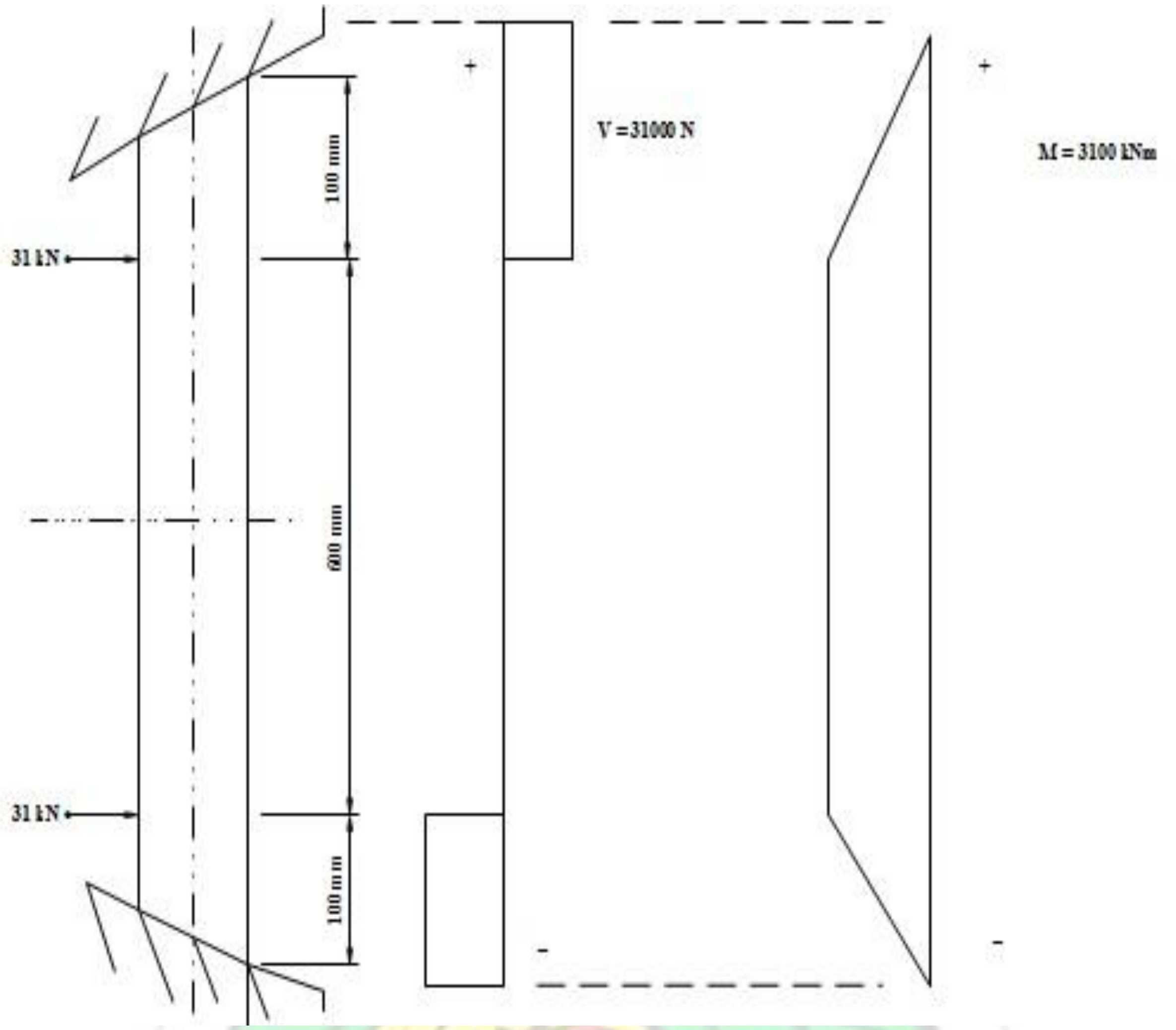


Figure 8. 3: Bending moment diagram for longitudinal section bar

If the yield strength for steel (σ_y) = 250 MPa

The Modulus of Elasticity (E) = 207 MPa

Then $\sigma_{allowable} = \sigma_y / n$

Where n is safety factor = 3.5

$\sigma_{allowable} = 250/3.5$

$\sigma_{allowable}$ =71.43 N/mm-2 if

L = 600 mm$_o$

Therefore using the equation $L \approx L_o(1+\frac{\sigma}{E})$

$$L \approx 600\,(1+\frac{71.43}{207})$$

$\approx$ 807 mm

to obtimize the design 800 mm was selected as the length of the outer leg

$M_{allowable} = \frac{\sigma_{allowable} \times I_{xx}}{y} = \frac{(71430\ Nm^{-2} \times 2256666.7mm^4)}{22.5\ mm} \approx 716416.5$ kNm

$M_{allowable} > M_{actual}$ the harvester frame transverse bar is safe for bending

Frame longitudinal section side bar (3)

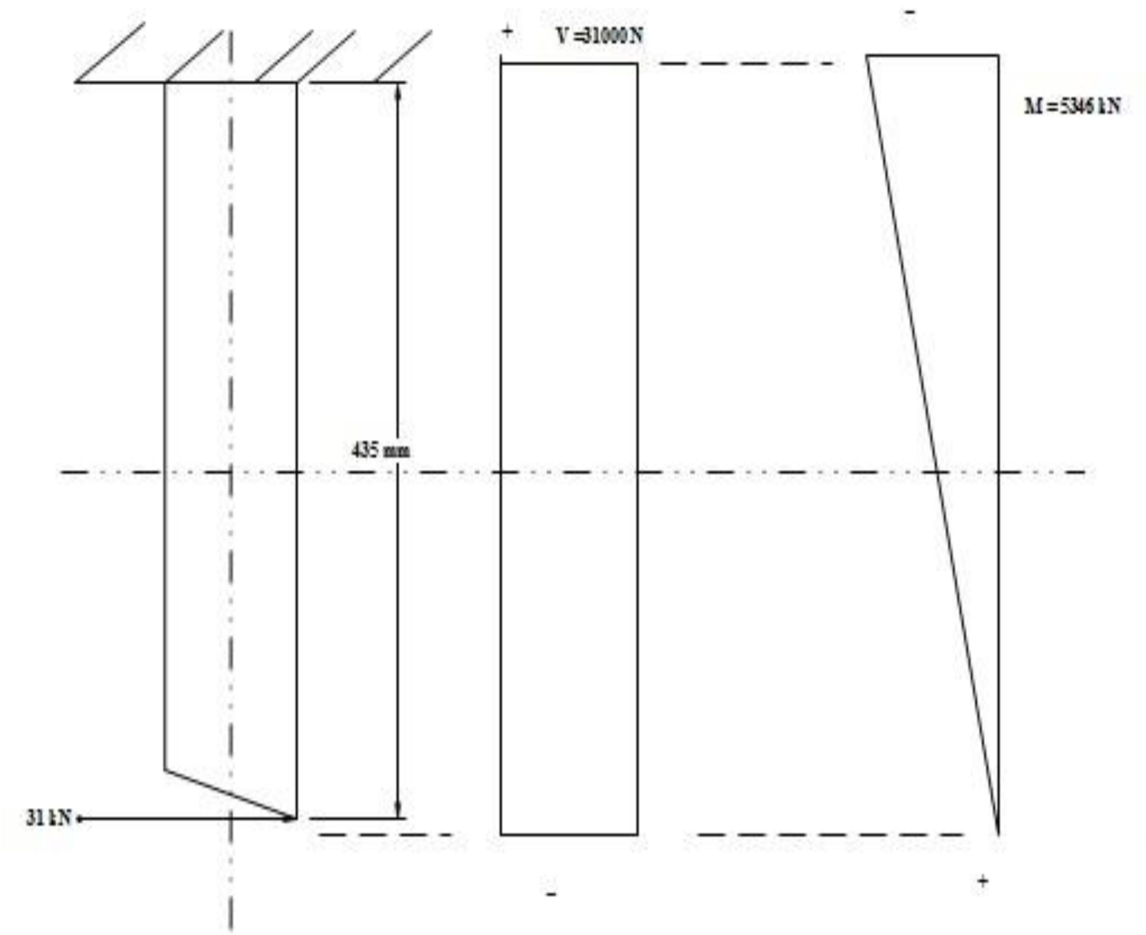


Figure 8. 4: Bending and shear moment diagram for longitudinal section side leg

If the yield strength for steel (□$_y$) = 250 MPa

The Modulus of Elasticity (E) = 207 MPa

Then $\sigma_{allowable}$ = □$_y$ /n

Where n is safety factor = 3.5

□$_{allowable}$ =250/3.5

□$_{allowable}$ =71.43 N/mm$_{-2}$ if

L = 300 mm$_o$

Therefore using the equation $L \square L(1+_{o}\frac{\sigma}{E})$

$$L \square 320\,(1\square \frac{71.43}{207})$$

$\square$ 430.4 mm

to obimize the design 435 mm was selected as the length of the outer leg

$M_{allowable} = \sigma_{allowable\ XX} I = $ ______________________________ (71430 $Nm^{\square 2}$

$\square$2256666.7mm $)_4 \square$ 716416.5 kNm y 22.5 mm

$M_{allowable} > M_{actual}$ the harvester frame transverse bar is safe for bending

Frame transverse back bar (4)

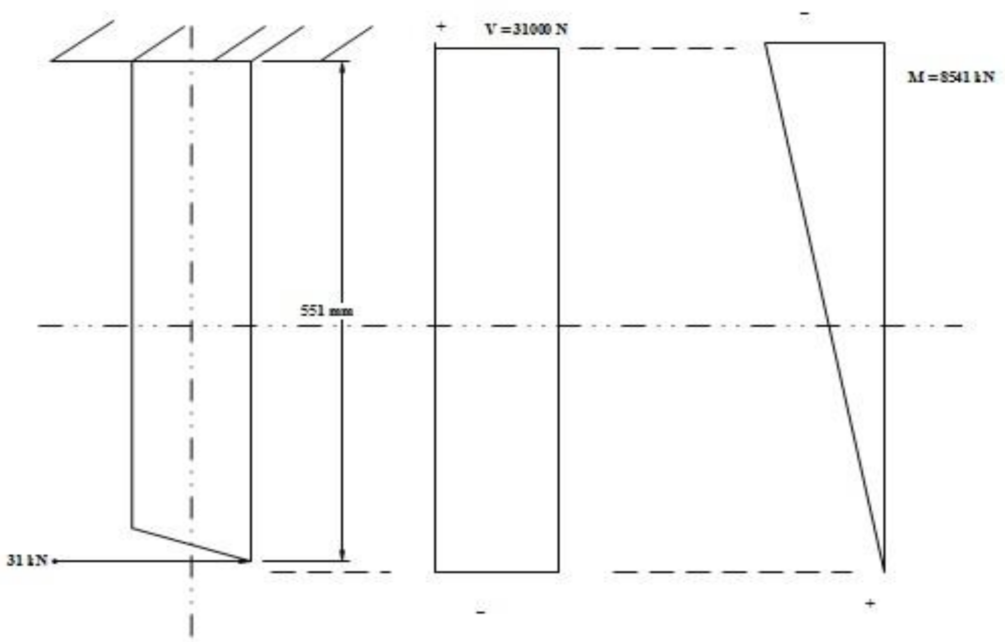


Figure 8. 5 Bending and shear moment diagram for the transverse back frame bar

If the yield strength for steel (σ_y) = 250 MPa

The Modulus of Elasticity (E) = 207 MPa

Then $\sigma_{allowable} = \sigma_y / n$

Where n is safety factor = 3.5

$\sigma_{allowable} = 250/3.5$

$\sigma_{allowable} = 71.43\ N/mm^{-2}$ if

$L = 300\ mm_o$

Therefore using the equation $L = L_o(1+\frac{\sigma}{E})$

$$L = 410\left(1 + \frac{71.43}{207}\right)$$

$= 551.45$ mm

to obtimize the design 551 mm was selected as the length of the outer leg

$M_{allowable} = \sigma_{allowable}$ XXI = (71430 Nm□2

□2256666.7mm)4 □ 716416.5 kNm y 2250 mm

$M_{allowable} > M_{actual}$ the harvester frame transverse bar is safe for bending

VQIt = 2256666.731000 N×52344 mm mm ×10 mm4 3 = 71.91 Nmm^{-2}
□□

T]o determine bolt size required for high grade class of fasteners (class 8.8)

But

F = $_s\tau$ × area =71.91 Nmm^{-2}□1700 mm^2 □122 kN

From appendix: 6 (e) choosing a safety factor ($f_{s.factor}$) = 3.5

preload force (F)= f ×shear force (F)=122s s 000 N×3.5 = 427000 N

From appendix: 6 (f) the maximum permissible share stress is =200 MPa (assume bolt diameter is less than 16 mm in diameter)

$$\text{shear area } (A_s) = \frac{F}{f_s} = \frac{427000}{200} = 2135\ mm^2$$

$$\text{but } A_S = \frac{\pi}{4} d^2 \Rightarrow d = \sqrt{\frac{4 \times 2135}{\pi}} = 52.1\ mm$$

From appendix: 6 (b) M 48 bolt is the nearest that is used and with a recommended assembly torque of 2064 Nm from appendix: 6 (d). M 14 bolts were used since such forces will not be reached.

For commercial grade class of fasteners (class 4.6) using a normal tensile force of 31000 N

From appendix: 6 (e) using a safety factor (f_s) = 3.5

$$\text{preload force } (F_i) = f_s \, \textit{tensile force } (F_t) = 31 \text{ kN} \times 3.5 = 108500 \text{ N}$$

From appendix: 6 (f) the maximum yield stress = 240 MPa

The maximum yield stress is used as the preload force

$$f_t = 240$$

$$\text{tensile area } (A_t) = \frac{F}{f_t} = \frac{108500}{240} = 452 \text{ mm}^2$$

Select a bolt size from appendix: 6 (a) which is M 24 and with a recommended assembly torque of 248 Nm from appendix: 6 (c). since the full force of the tractor will not be used, M16 bolts were used.

Harvester le

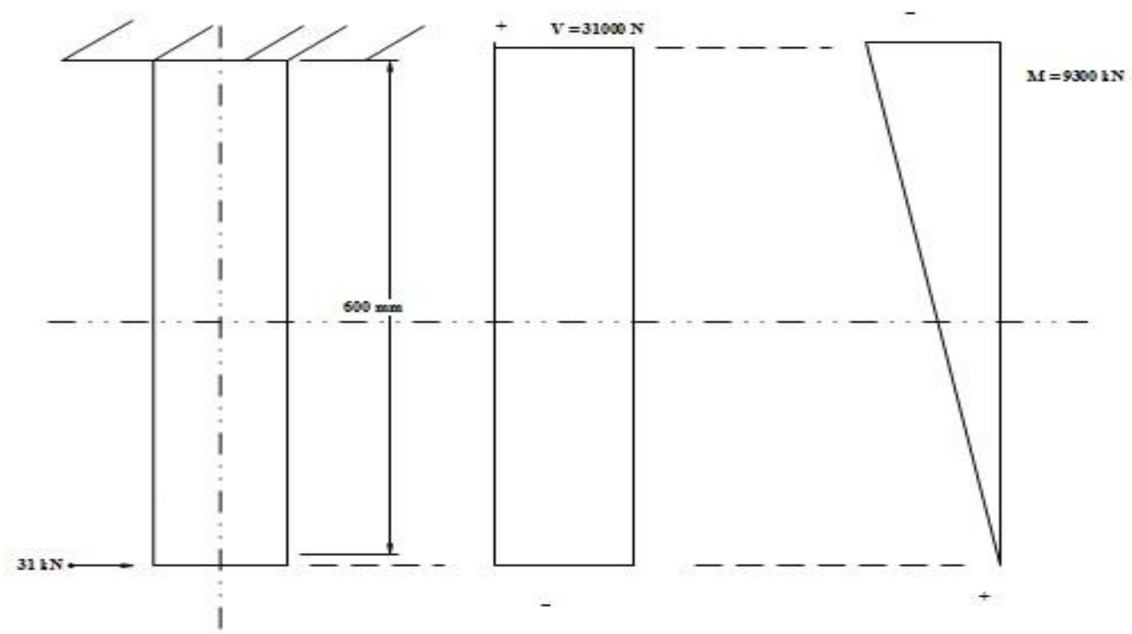


Figure 8. 6: Shear and bending moment diagram for the harvester leg

If the yield strength for steel (□$_y$) = 250 MPa

The Modulus of Elasticity (E) = 207 MPa

Then $\sigma_{allowable}$ = □$_y$ /n

Where n is safety factor = 3.5

□$_{allowable}$ =250/3.5

□$_{allowable}$ =71.43 N/mm$_{-2}$ if

L = 460 mm$_o$

Therefore using the equation L □ L (1+$_o$ $\frac{\sigma}{E}$)

L □ 500 (1□ $\frac{71.43}{207}$)

□ 618 mm

to obtimize the design 630 mm was selected as the length of the outer leg

If the tractor provides 43kN of power (maximum)

Legs are flat bars with cross sectional area as

A 100 mm ×10 mm =1000 mm²

Table 8. 5: Parameter for obtaining share force of legs with reference to the centroidal axis

About x-axis	a(mm²)	y(mm)	ay(mm³)	d(mm)	ad²(mm⁴)	Io(mm⁴)
	1000	5	5000	5	25000	8333.33
About y-axis	a(mm²)	y(mm)	ay(mm³)	d(mm)	ad²(mm⁴)	Io(mm⁴)
	1000	50	50000	0	0	83333.33

$$I_o = \frac{bh^3}{12} = \frac{100mm(10mm)^3}{12} = 8333.33mm^4$$

about y- axis

$$I_o = \frac{bh^3}{12} = \frac{10mm(100mm)^3}{12} = 83333.33mm^4$$

$I_{xx} = \sum I_o$ 8333.33 = 8333.33 + 25000 = 33333.33 $\sigma_{allowable\ xx}I$ = (71430

Nm⁻² 3333.33 mm⁴)

= 47619.95 kNm

$M_{allowable}$ =

y 5 mm

$M_{allowable} > M_{actual}$ the harvester leg is safe for bending

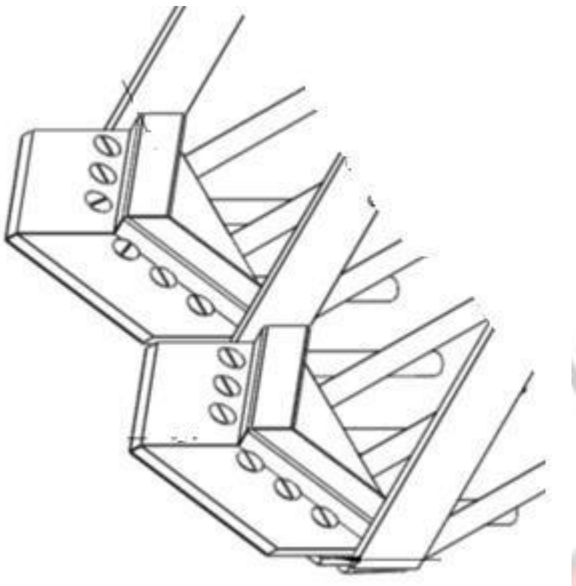


Figure 8. 7: The blade

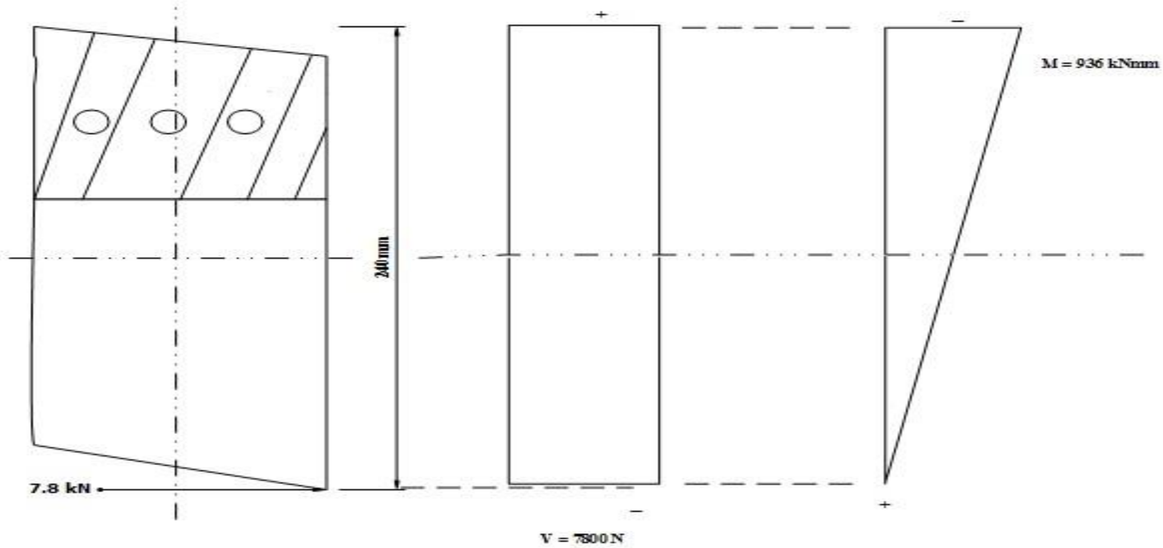


Figure 8. 8 Bending and shear moment diagram for harvester blade

If the yield strength for steel (σ_y) = 250 MPa

The Modulus of Elasticity (E) = 207 MPa

Then $\sigma_{allowable} = \sigma_y / n$

Where n is safety factor = 3.5

$\sigma_{allowable} = 250/3.5$

$\sigma_{allowable}$ = 71.43 N/mm-2 if

L = 170 mm_o

Therefore using the equation $L = L_o(1+\frac{\sigma}{E})$

$L = 170\,(1 + \frac{71.43}{207})$

$= 228.7$ mm

to obtimize the design 230 mm was selected as the length of the outer leg Table 8. 6: Parameters for obtaining moment of inertia about a point of the blade

x-axis	a(mm²)	y(mm)	ay(m³)	d(m)	ad²(m⁴)	Iₒ(m⁴)
	2604	6	21624	6	93744	31248
y-axis	2604	108.5	282534	0.00	0.00	10218313

$\bar{y} = \frac{\sum ay}{\sum a} = \frac{14400}{2400} = 6$

if $I_o = \frac{bh^3}{12}$

$I_{xx} = \sum I_o + ad^2 = 31248mm^4 + 93744mm^4 = 124992mm^4$

$I_{YY} = \sum I_o + ad^2 = 10218313mm^4 + 0.00mm^4 = 10218313mm^4$

$M_{allowable} = \frac{\sigma_{allowable}\, I_{XX}}{y} = \frac{(71430\ Nm^{-2} \times 124992\ mm^4)}{6\ mm} = 1488029.95$ kNm

$M_{allowable} > M_{actual}$ the harvester leg is safe for bending

$$S_{\min} = \frac{M}{0.9\sigma_y n} = \frac{(936 \text{ kNmm})}{(0.9 \times 250 \; 3.5)} = 1188.57 \text{ Nmm}^{-2}$$

Where $S_{\min}$ = minimum allowable sectional modulus

$$t = \sqrt{\frac{6 S_{\min}}{w}} = \sqrt{\frac{(6 \times 1188.57 \text{ Nmm}^{-2})}{136 \text{ mm}}} \Rightarrow t \; 7.2 \text{ mm}$$

t = thickness and w = effective width to allow for contingencies 12 mm plates were used for the design.

$$\tau = \frac{VQ}{It} = \frac{7800 \text{ N} \times 21624 \text{ mm}^3}{124992 \text{ mm} \times 12 \text{ mm}^4} = 112.5 \text{ Nmm}^{-2}$$

If the shear force derived with the draught force if transferred to the bolts used to fasten the blade in position.

$$F = {}_s\tau \times \text{area} = 112.5 \text{ Nmm}^{-2} \times 2604 \text{ mm}^2 = 293 \text{ kN}$$

To determine bolt size required for high grade class of fasteners (class 8.8)

From appendix: 6 (e) choosing a safety factor ($f_{S.factor}$) = 3.5

$$\text{preload force (F)} = f_{S..factor} \times \text{shear force } (F_S) = 3.5 \times 293000 \text{ N} = 1025 \text{ kN}$$

From appendix: 6 (f) the maximum design capacity share stress is = 396.8 MPa (assume bolt diameter is less than 16 mm in diameter)

$$\text{shear area } (A_s) = \frac{F}{f_s} = \frac{1025500}{396.8} = 2584.4 \text{ mm}^2$$

$$\frac{\pi d^2}{4} \quad 4\times\sqrt{\frac{2584.4}{\pi}} \quad \text{but } A =_s \quad Þd= =51.3 \text{ mm}$$

From appendix: 6(b) M 48 bolt is the nearest that is used and with a recommended assembly torque of 5500 Nm from appendix: 6(d). M 12 bolts were used since such high forces from the tractor will not be reached.

For commercial grade class of fasteners (class 4.6) using a normal tensile force of 7800 N

From appendix: 6 (e) using a safety factor (f_s) = 3.5 preload force (F) = f ×tensile force (F) $_{s\,t}$= 7.8 kN×3.5= 27300 N

From appendix: 6(f) the maximum yield stress = 240 MPa

f_t 240

$$\text{tensile area } (A_t) = \frac{F}{f_t} = \frac{27300}{240} = 113.7 \text{ mm}^2$$

Select a bolt size from appendix: 6(a) with the above tensile area which is M 14 and with a recommended assembly torque of 47 Nm from appendix: 6 (c)

Appendix 5.2: Selection of material

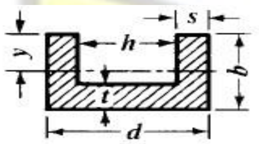
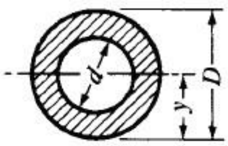
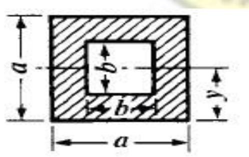
Reason for selecting shape (cross-section of material) of material using Ashby's method of shape selection (Ashby, 1999).

The constraints was that the part:

1. must bend before braking

L = 200 mm

Table 8. 7: Material shape selection

Cross-section of material	Dimensions	I (mm^4)	Constraint = $\square_{Bf}\square_{f} \frac{M}{M_{fo}}$
c- sectional bar 	4500 10000□ mm and t= 10 mm	$\frac{2}{3} a t^2$	22.5
Hollow round bar 	d= 2400 mm, t= 6 mm	$2\square rt$	12
Hollow bar 	10000 10000□ mm pipe and t= 10 mm	$\frac{2}{3} a t^2$	5

$$\phi_{Bf} = \frac{M_f/\sigma_y Z}{M_{fo}/\sigma_y Z_o}$$

Z is sectional modulus part of member

Z_o sectional modulus at reference point

For c-channel

$$\frac{Z}{Z_o} = \frac{\left(\frac{2256666.7mm^4}{100mm}\right)}{\left(\frac{2256666.7mm^4}{2250mm}\right)} = 22.5$$

For hollow pipe

$$\frac{Z}{Z_o} = \frac{\left(\frac{2.356 \times 10^{11} mm^4}{100mm}\right)}{\left(\frac{2.356 \times 10^{11} mm^4}{1200mm}\right)} = 12$$

For hollow bar

$$\frac{Z}{Z_o} = \frac{\left(\frac{6666666667mm^4}{100mm}\right)}{\left(\frac{6666666667mm^4}{5000mm}\right)} = 5$$

C-channel has the highest shape factor for failure at bending. Therefore, c-channel was used for the construction of the design.

Appendix

6(a): Commercial grade class bolts based on breaking and yield loads

Breaking and Yield Loads of Ajax Bolts and Set Screws

Ajax Metric Hexagon Commercial Bolts and Set Screws
(AS 1111-1996/AS 4291.1-1995 Property Class 4.6)

Based on:

Tensile Strength = 400 MPa min (58015 lbf/in²)
Yield Stress = 240 MPa min (34810 lbf/in²)
Proof Load Stress = 225 MPa (32635 lbf/in²)

Size	Tensile Stress Area of Thread*	Proof Load of Bolt		Breaking Load of Bolt (Min.)	
	mm²	kN	lbf	kN	lbf
M5	14.2	3.20	719	5.68	1275
M6	20.1	4.52	1015	8.04	1805
M8	36.6	8.24	1850	14.6	3280
M10	58.0	13.0	2920	23.2	5215
M12	84.3	19.0	4270	33.7	7575
M14	115	25.9	5820	46.0	10300
M16	157	35.3	7940	62.8	14120
M18	192	43.2	9710	76.8	17250
M20	245	55.1	12390	98.0	22030
M22	303	68.2	15450	121	27200
M24	353	79.4	17850	141	31700
M27	459	103	23200	184	41400
M30	561	126	28330	224	50360
M33	694	156	35100	278	62500

continued

Size	Tensile Stress Area of Thread*	Proof Load of Bolt		Breaking Load of Bolt (Min.)	
	mm²	kN	lbf	kN	lbf
M36	817	184	41370	327	73510
M39	976	220	49500	390	87700
M42	1120	252	56650	448	100710
M48	1470	331	74410	588	132190
M56	2030	458	102960	812	182550
M64	2680	605	136000	1072	241000

Source:Ajax Fasteners Hand book. New Edition, (1999). 6(b): High grade class bolts based on breaking and yield load

Appendix

Breaking and Yield Loads of Ajax Bolts and Set Screws

Ajax Metric Hexagon Precision
Bolts and Set Screws
(AS 1110-1995/ AS 4291.1-1995 Property Class 8.8)

		Based on:		
Tensile Strength	=	800 MPa min	(116030 lbf/in²)	Sizes M5 – M16 incl.
	=	830 MPa min	(120380 lbf/in²)	Sizes M18 – M39 incl.
Yield Stress	=	640 MPa min	(92825 lbf/in²)	Sizes M5 – M16 incl.
	=	660 MPa min	(95725 lbf/in²)	Sizes M18 – M39 incl.
Proof Load Stress	=	580 MPa	(84120 lbf/in²)	Sizes M5 – M16 incl.
	=	600 MPa	(87025 lbf/in²)	Sizes M18 – M39 incl.

Size	Tensile Stress Area of Thread*	Proof Load of Bolt		Breaking Load of Bolt (Min.)	
	mm²	kN	lbf	kN	lbf
M5	14.2	8.23	1850	11.35	2550
M6	20.1	11.6	2610	16.1	3620
M8	36.6	21.2	4770	29.2	6560
M10	58.0	33.7	7580	46.4	10430
M12	84.3	48.9	10990	67.4	15150
M14	115	66.7	14995	92	20680
M16	57	91.0	20460	125	28100
M18	192	115	25850	159	35745
M20	245	147	33050	203	45640
M22	303	182	40915	252	56650
M24	353	212	47660	293	65870
M27	459	275	61820	381	85650

continued

Size	Tensile Stress Area of Thread*	Proof Load of Bolt		Breaking Load of Bolt (Min.)	
	mm²	kN	lbf	kN	lbf
M30	561	337	75760	466	104760
M33	694	416	93520	576	129490
M36	817	490	110160	678	152420
M39	976	586	131740	810	182100

Source: Ajax Fasteners Hand book**.** New Edition, (1999).

6(c): Commercial grade bolts with tightening torque

Appendix

Tightening of Bolted Joints

Recommended Assembly Torques

Bolt Type	Diameter mm	Bolt Tension Corresponding to 65% of Proof Load kN	lbf	Recommended Assembly Torque Nm	lbft
AS 1111 Ajax Property Class 4.6 Commercial Low Tensile Bolts	5	2.08	468	2.1	1.5
	6	2.94	660	3.5	2.5
	8	5.34	1200	8.5	6.3
	10	8.45	1900	17	12
	12	12.4	2790	30	22
	14	16.8	3780	47	35
	16	22.9	5150	73	54
	18	28.1	6320	101	75
	20	35.8	8050	143	106
	22	44.3	9960	195	145
	24	51.6	11600	248	183
	27	67.0	15060	362	265
	30	81.9	18410	491	362
	33	101	22800	669	495
	36	120	26980	864	637
	39	143	32150	1115	820
	42	164	36870	1378	1020

Recommended Assembly Torques continued

Bolt Type	Diameter mm	Bolt Tension Corresponding to 65% of Proof Load kN	lbf	Recommended Assembly Torque Nm	lbft
AS 1111 Ajax Property Class 4.6 Commercial Low Tensile Bolts	48	215	48330	2064	1520
	56	298	66990	3338	2460
	64	393	88350	5030	3710

Source: Ajax Fasteners Hand book**.** New Edition, (1999).

6(d): High grade class bolts with tightening torque

Appendix

Tightening of Bolted Joints

Recommended Assembly Torques

Bolt Type	Diameter mm	Bolt Tension Corresponding to 65% of Yield Load kN	lbf	Recommended Assembly Torque Nm	lbft
AS 1110 Ajax Property Class 8.8 Precision High Tensile Bolts ISO Coarse Series Threads	5	5.4	1210	5	4
	6	7.6	1710	9	7
	8	13.8	3100	22	16
	10	21.9	4920	44	32
	12	31.8	7150	77	57
	14	43.4	9680	121	90
	16	59.2	13310	190	140
	18	74.8	16690	269	198
	20	95.6	21490	370	270
	22	118	26390	520	380
	24	138	31020	640	470
	27	177	39480	955	700
	30	219	49230	1310	970
	33	270	60330	1785	1320
	36	319	71710	2300	1690
	(39)	380	84980	2970	2190
	(42)	437	98240	3670	2710

Recommended Assembly Torques continued

Bolt Type	Diameter mm	Bolt Tension Corresponding to 65% of Yield Load kN	lbf	Recommended Assembly Torque Nm	lbft
AS 1110 Ajax Property Class 8.8 Precision High Tensile Bolts	(48)	573	128820	5500	4060
	(56)	792	178050	8870	6540
	(64)	1045	234930	13380	9870

Source: Ajax Fasteners Hand book**.** New Edition, (1999).

6(e): Safety factor

Appendix

Nature of Loading	Safety Factors*
Steady Stress	1.5 – 2
Repeated Stress gradually applied shock	 2 – 3.5 4.5 – 6

*Applies to joints with direct tensile loads only, and assumes all bolts are tightened to 65% of the yield stress.

Source: Ajax Fasteners Hand book**.** New edition, (1999).

Appendix 6(f): Bolt shear capacity

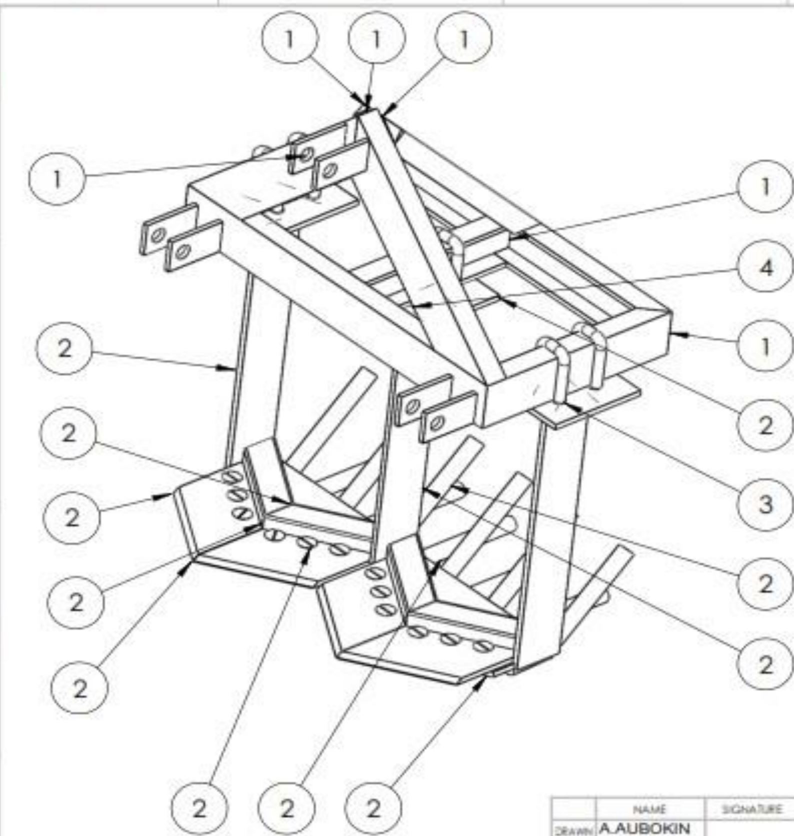
Bolt Shear Capacity of Ajax Bolts and Set Screws

Table 16

Bolt Type	Shear Stress at failure[1] (Mpa)		Ratio[2]	AS 1250-1981 Maximum Permissible Design Shear Stress (MPa)[4]	AS 4100-1990 Maximum "Design Capacity Shear Stress"[5] (MPa)
	Min	Max[3]			
AS 1111 Property Class 4.6	248.0	431.5	1.74	79.2	198.4
AS 2451 BSW Low Tensile 1/4" – 3/4"	267.8	452.6	1.69	(81.5)[6]	214.3
7/8" – 1"	267.8	452.6	1.69	(76.6)[6]	214.3
AS 1559 Tower Bolt	320.0[7]	—	—	112.2[8]	238.1[9]
As 1110 Property Class 5.8	322.4	431.5	1.34	130.0	257.9
AS 1110 Property Class 8.8 M1.6 – M16	496.0	636.1	1.28	200.0	396.8
M18 – M36	514.6	654.1	1.27	207.5	411.7
AS 2465 Unified Grade 5 1/4" – 1"	512.7	654.1	1.28	206.8	410.2
1.1/8" – 1.1/2"	448.9	589.6	1.31	181.0	359.1
AS2465 Unified Grade 8	641.0	752.1	1.17	258.5	512.9
AS 1110 Property Class 10.9	644.8	752.1	1.17	260.0	515.8

Source: Ajax Fasteners Hand book**.** New edition, (1999)

Appendix 7: Working drawings



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	1	5
	6	7
	2	1
	2	4
	2	3
2	1	
	1	13
	3	10
	2	8
	2	16
	2	17
	2	19
	6	15
	1	9
	2	18
	5	14
	12	20
	12	21
3	6	11
4	12	12

	NAME	SIGNATURE	DATE
DRAWN	A.AUBOKIN		
CHK'D	J.AVEYIRE		
APPV'D	J.AVEYIRE		
MFG	K.N.U.S.T		
Q.A			

TITLE: Harvester base Assemly

MATERIAL: **MILD STEEL**

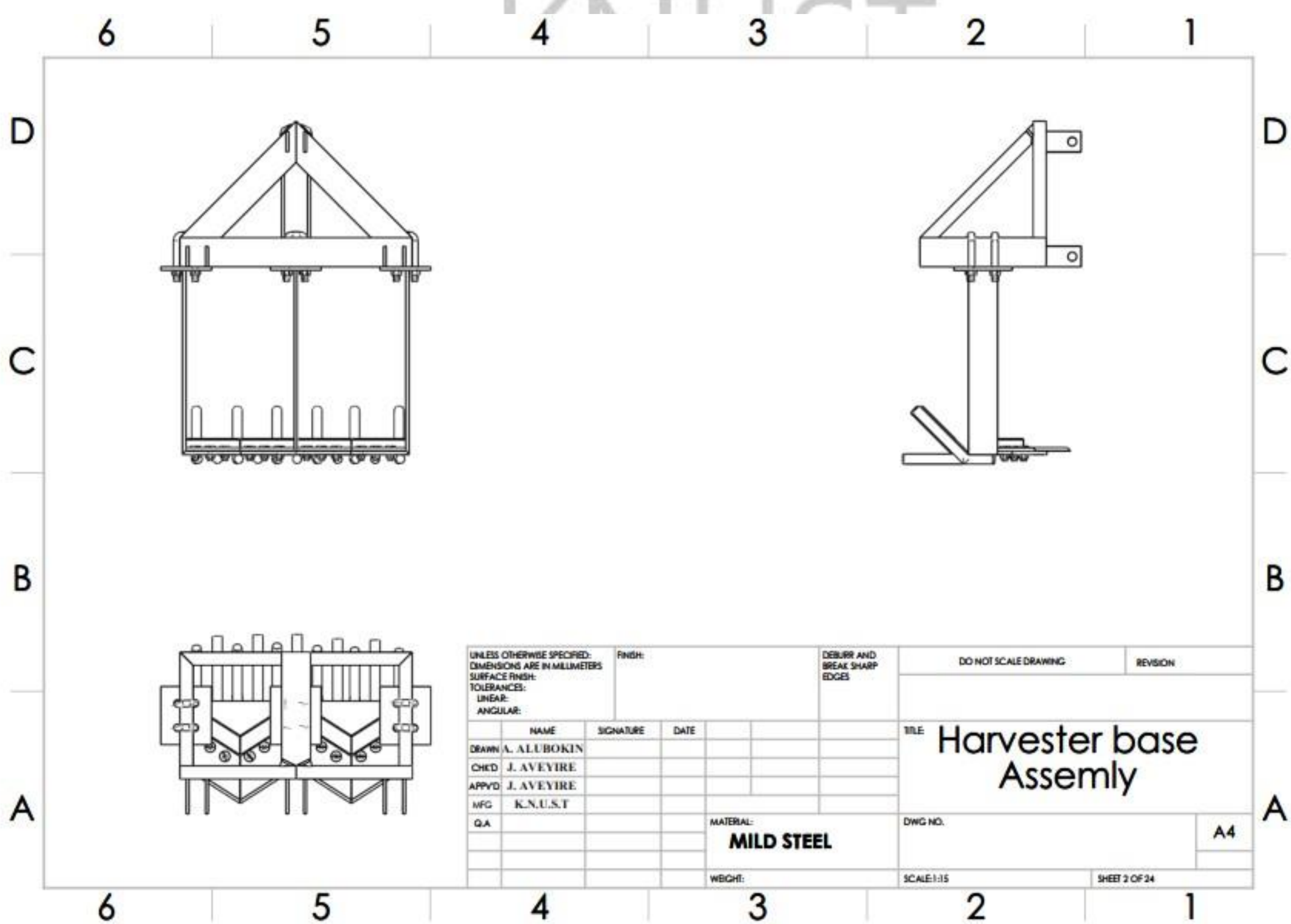
DWG NO.

A4

WEIGHT:

SCALE:1:20

SHEET 1 OF 24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ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A. ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
MATERIAL:
MILD STEEL
WEIGHT:
TITLE:
Harvester base Assemly
DWG NO.
A4
SCALE:1:15
SHEET 2 OF 24

ITEM NO.	QTY.	PART NO
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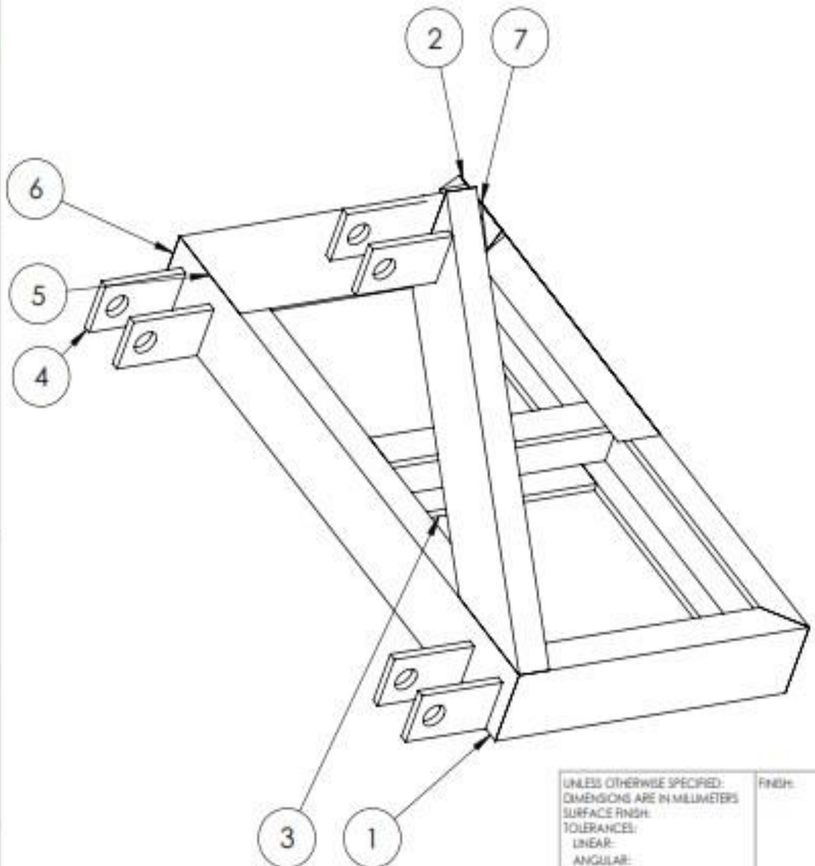
7	2	3



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FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	A. ALUBOKIN		
CHK'D	J. AVEYIRE		
APPV'D	J. AVEYIRE		
MFG	K.N.U.S.T		
Q.A			

TITLE: **Harvester base Assemly**

MATERIAL: **MILD STEEL**

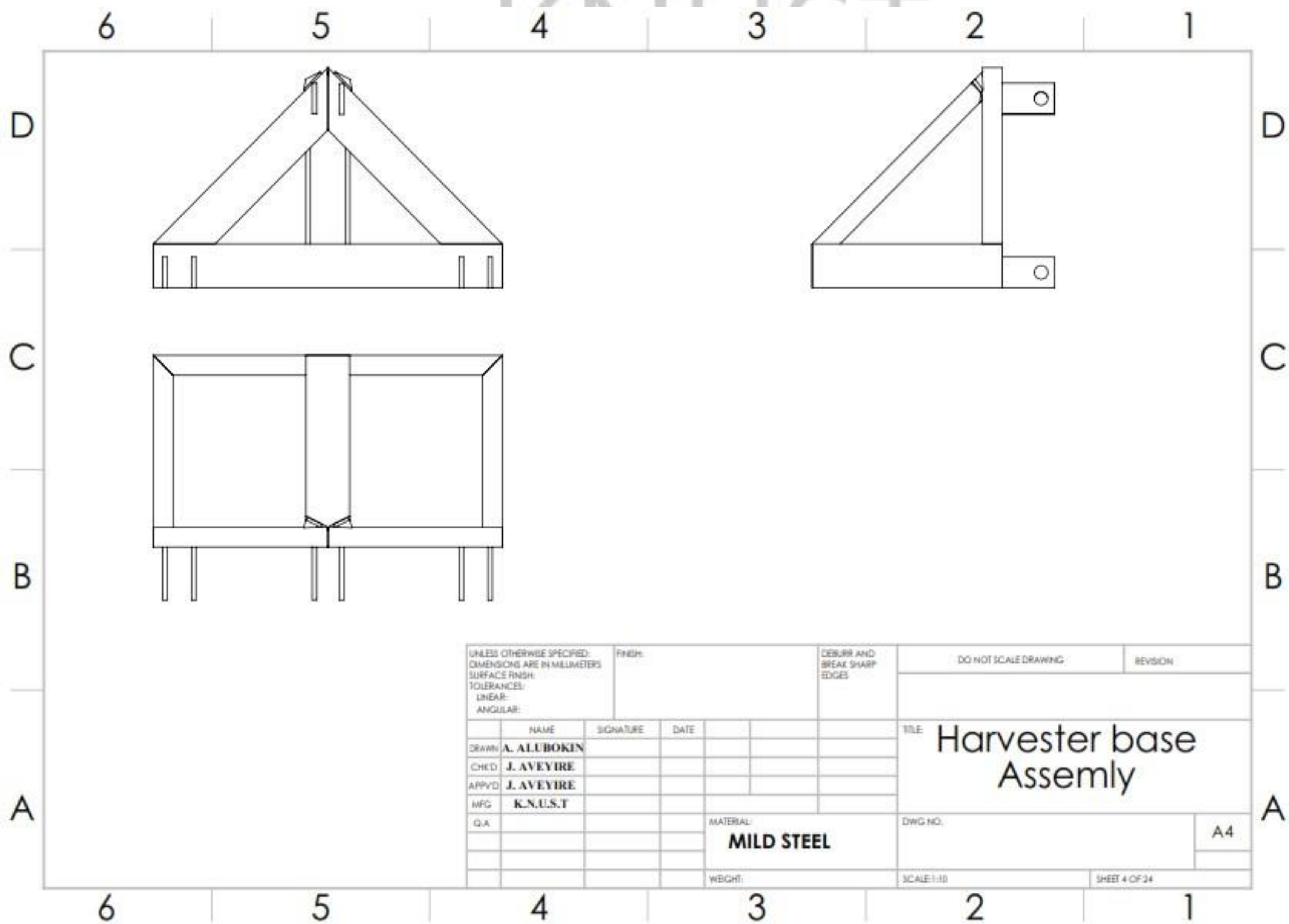
DWG NO.

A4

WEIGHT:

SCALE:1:7

SHEET 3 OF 24



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LINEAR:
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FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A. ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
TITLE: Harvester base Assemly
MATERIAL: MILD STEEL
DWG NO.
A4
WEIGHT:
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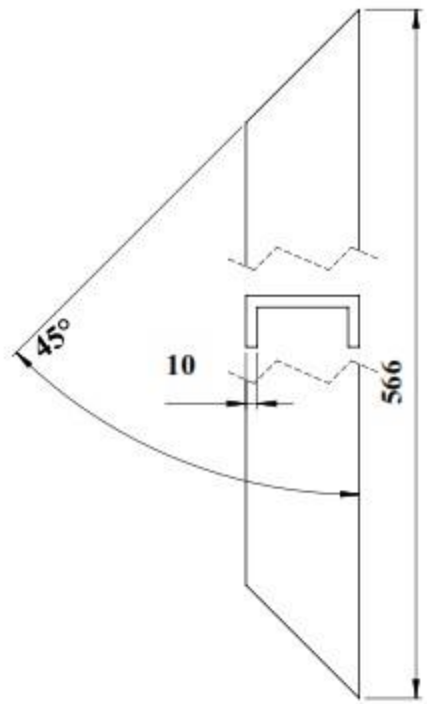
SHEET 4 OF 24



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FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	**A. ALUBOKIN**		
CHK'D	**J. AVEYIRE**		
APPV'D	**J. AVEYIRE**		
MFG	**K.N.U.S.T**		
Q.A			

TITLE:

FRAME TRANSVERSE SECTION BAR

MATERIAL:

MILD STEEL

DWG NO.

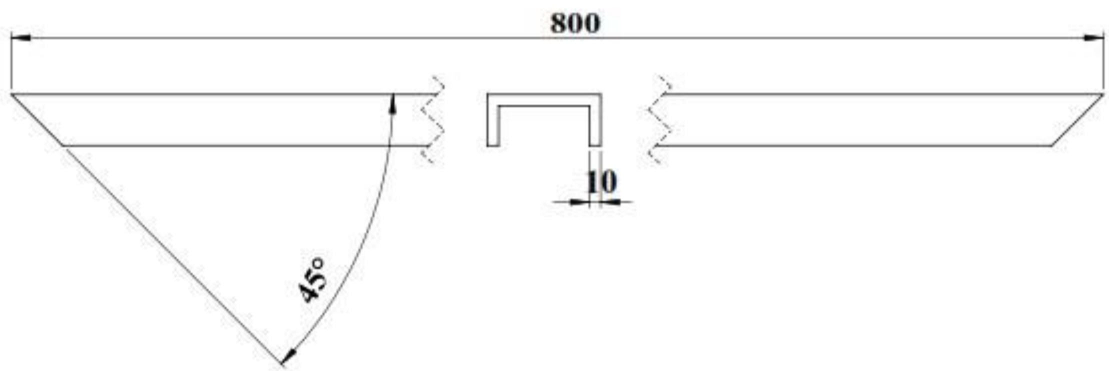
1

A4

WEIGHT:

SCALE:1:5

SHEET 5 OF 24



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	NAME	SIGNATURE	DATE
DRAWN	A. ALUBOKIN		
CHK'D	J. AVEYIRE		
APPV'D	J. AVEYIRE		
MFG	K.N.U.S.T		
Q.A			

TITLE: **FRAME LONGITUDINAL SECTION BAR**

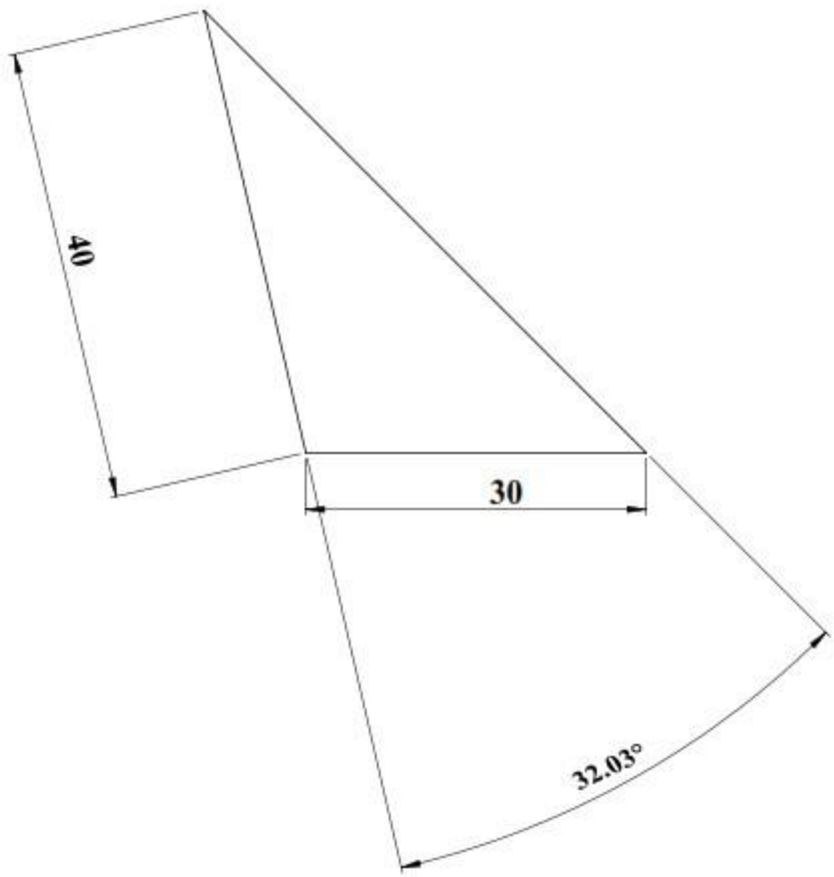
MATERIAL: **MILD STEEL**

DWG NO. **2** — A4

WEIGHT:

SCALE1:5

SHEET 6 OF 24



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	NAME	SIGNATURE	DATE
DRAWN	A. ALUBOKIN		
CHK'D	J. AVEYIRE		
APPV'D	J. AVEYIRE		
MFG	K.N.U.S.T		
Q.A			

TITLE:

BRACE

MATERIAL: **MILD STEEL**

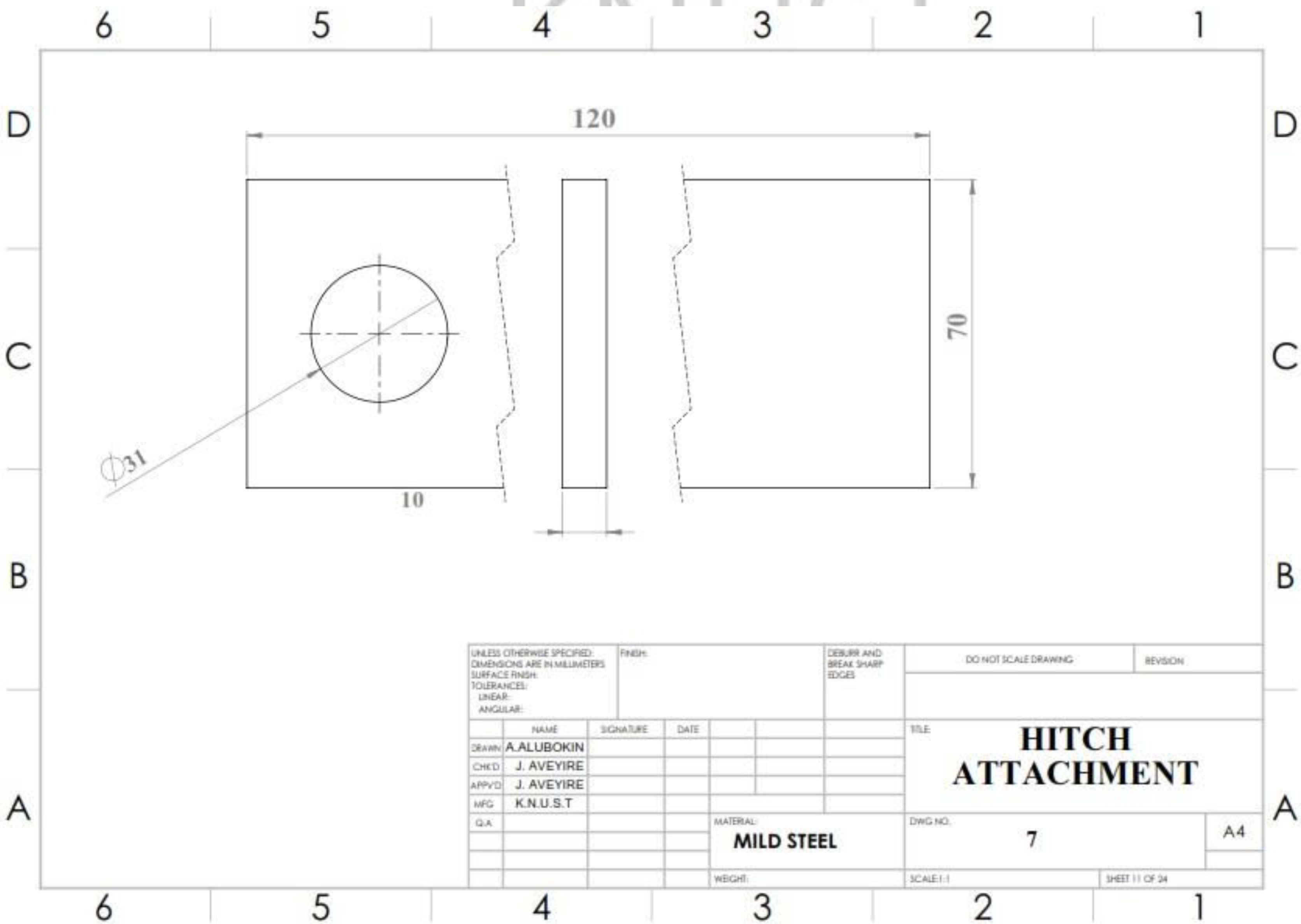
DWG NO. **3**

A4

WEIGHT:

SCALE:2:1

SHEET 7 OF 24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TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A.ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
TITLE:
HITCH ATTACHMENT
MATERIAL:
MILD STEEL
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7
A4
WEIGHT:
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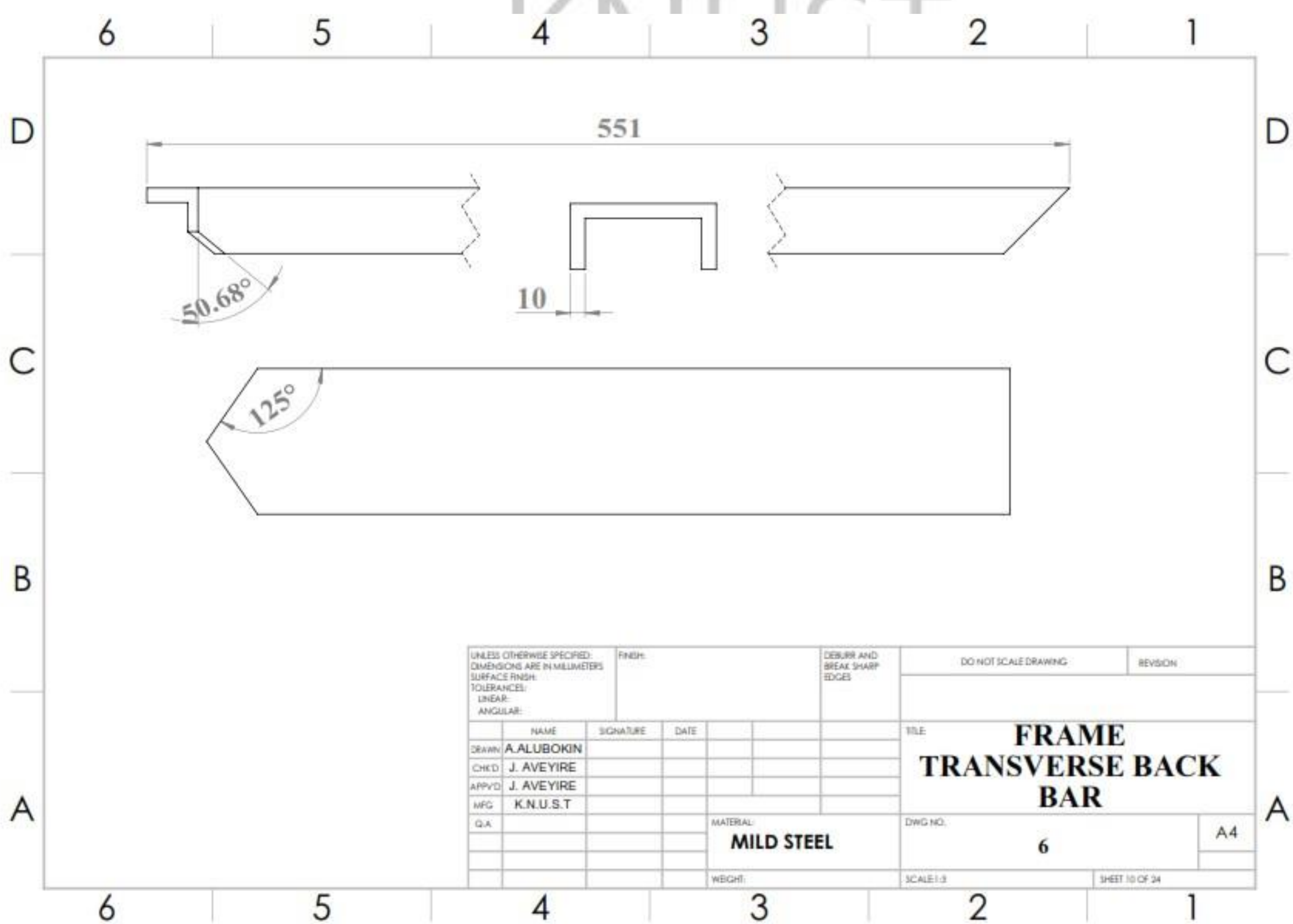
SHEET 11 OF 24



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TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A.ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
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TITLE:
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WEIGHT:
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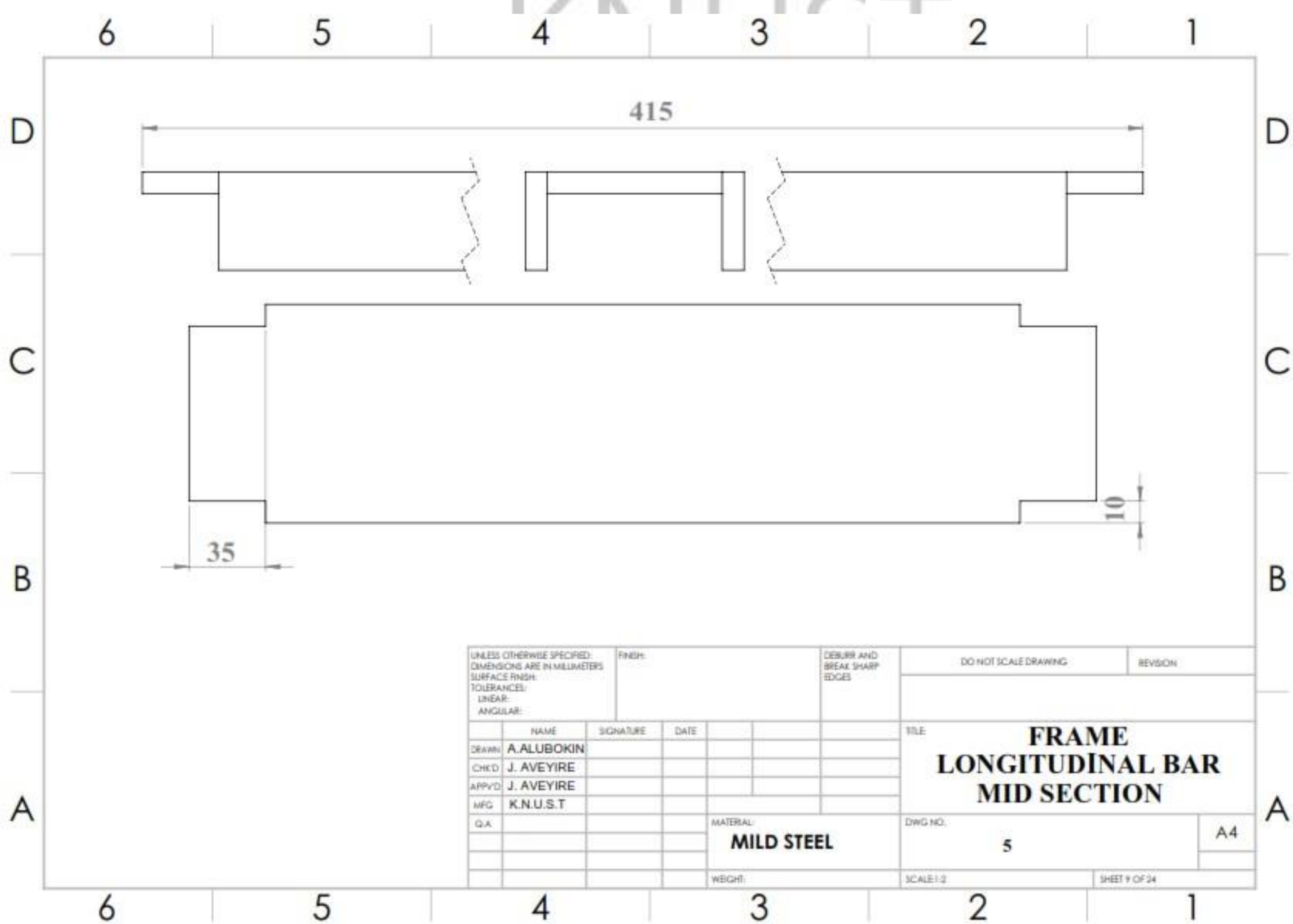
SHEET 10 OF 24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LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A.ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
TITLE:
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LONGITUDINAL BAR
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MATERIAL:
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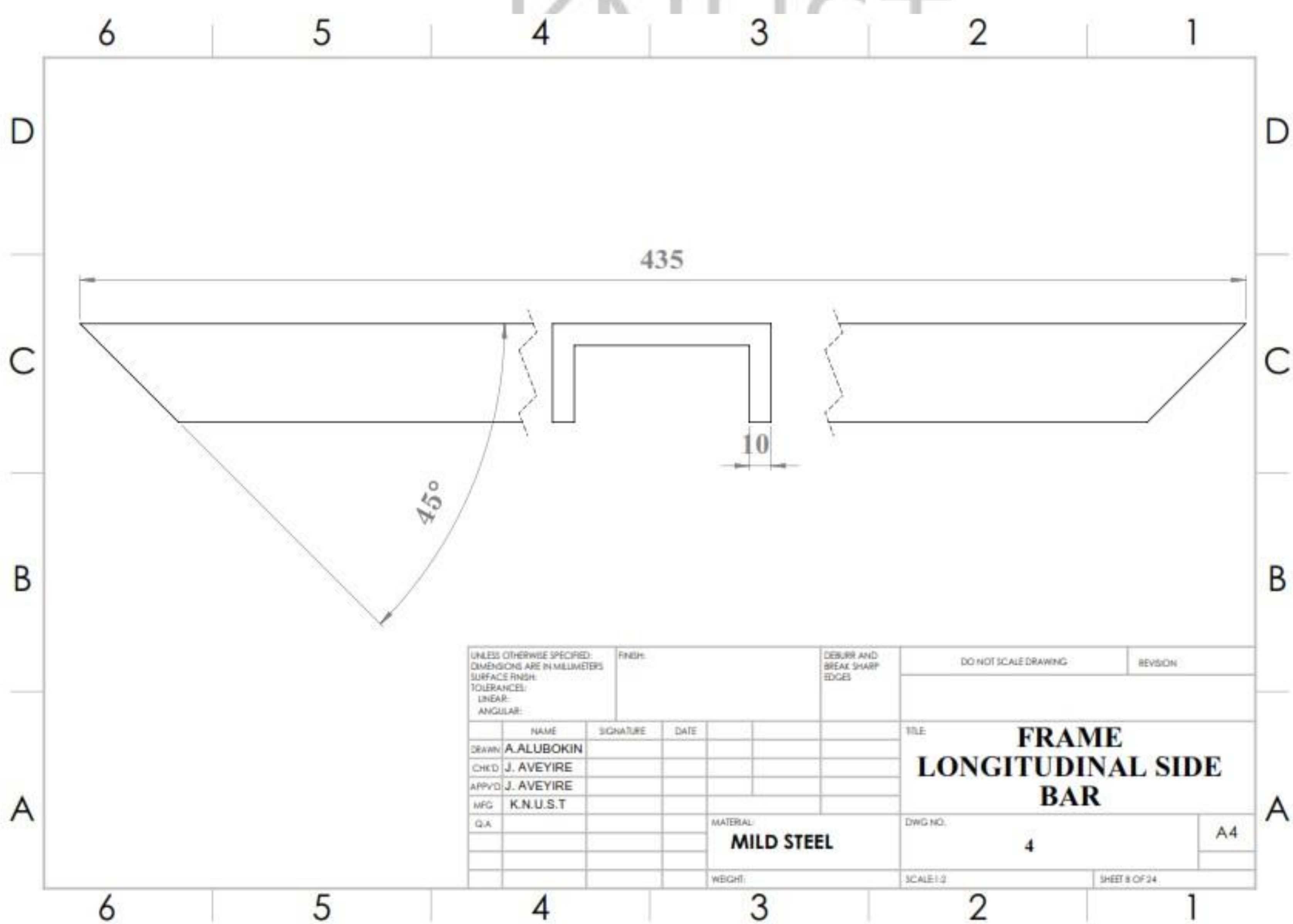
WEIGHT:
SCALE:1:2
SHEET 9 OF 24



435
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TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A.ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
MATERIAL:
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WEIGHT:
TITLE:
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DWG NO.
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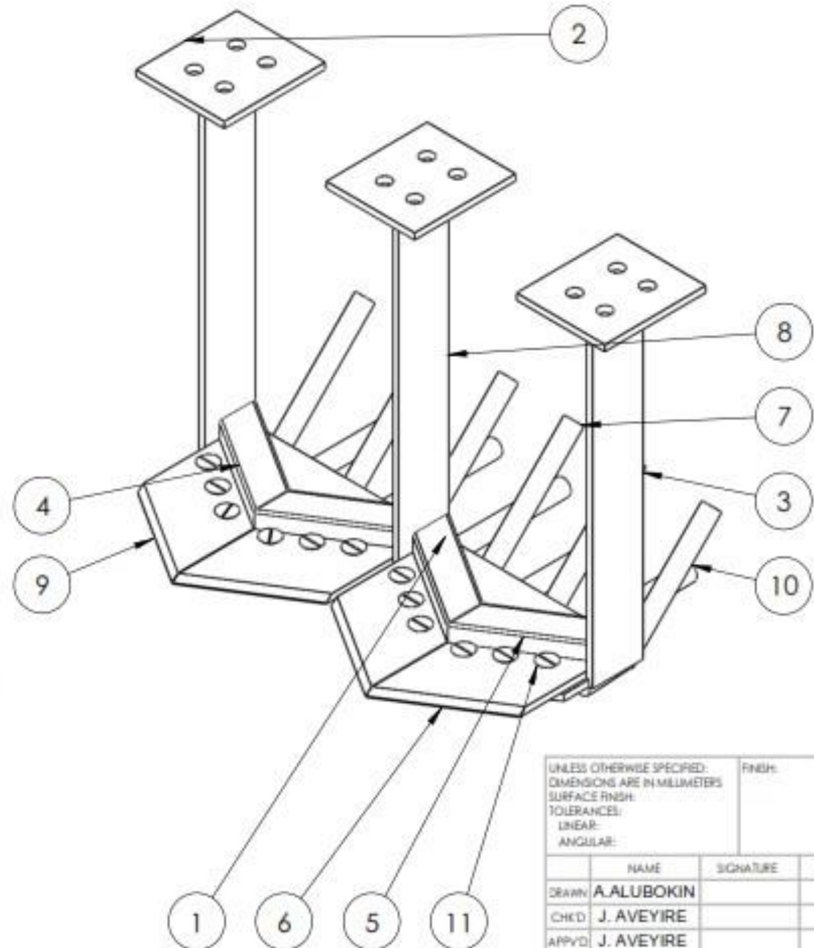
SHEET 8 OF 24



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12	12	21

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	A.ALUBOKIN		
CHK'D	J. AVEYIRE		
APPV'D	J. AVEYIRE		
MFG	K.N.U.S.T		
Q.A			

TITLE: Harvester base Assemly

MATERIAL: **MILD STEEL**

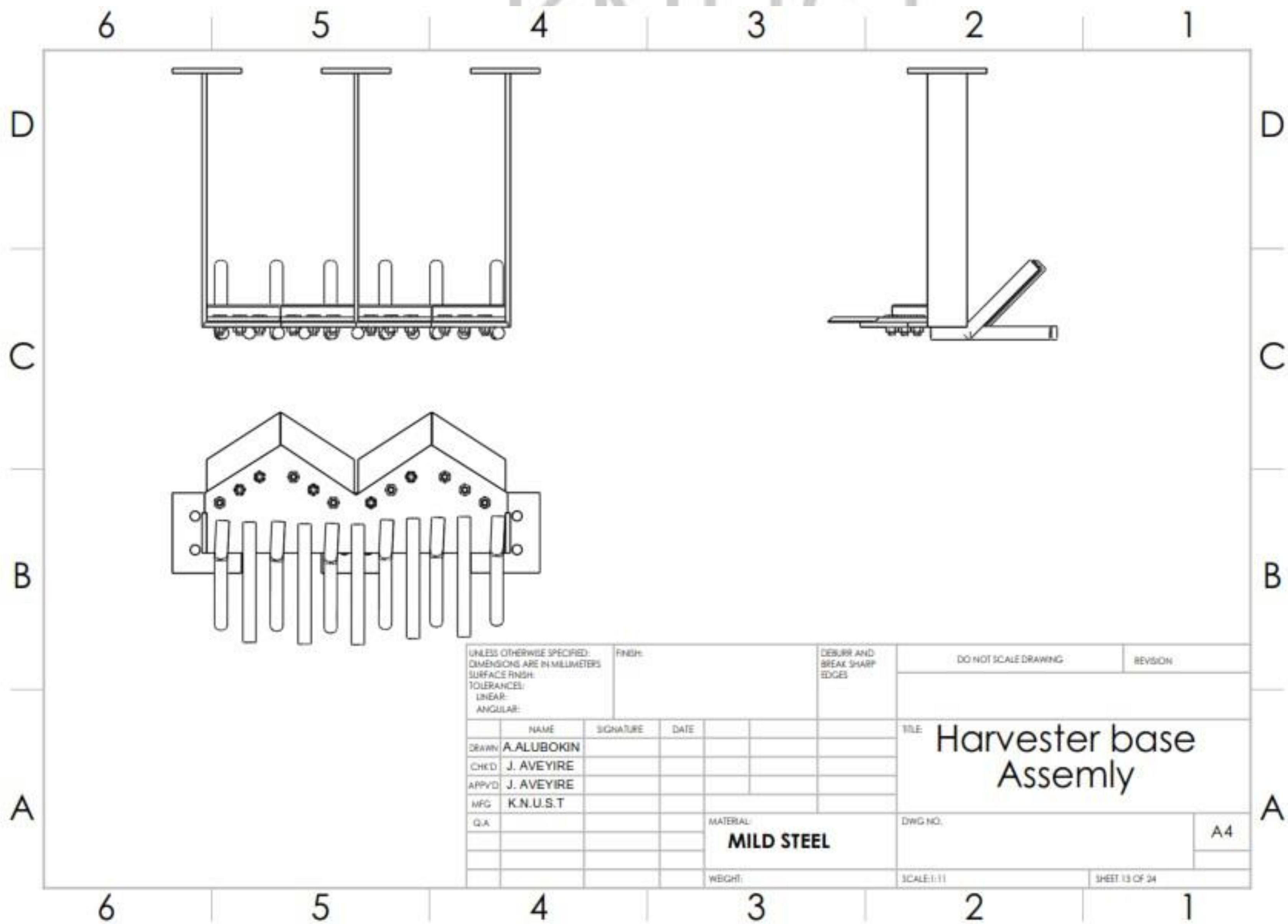
DWG NO.

A4

WEIGHT:

SCALE:1:8

SHEET 12 OF 24



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FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A.ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
TITLE: Harvester base Assemly
MATERIAL: MILD STEEL
DWG NO.
A4
WEIGHT:
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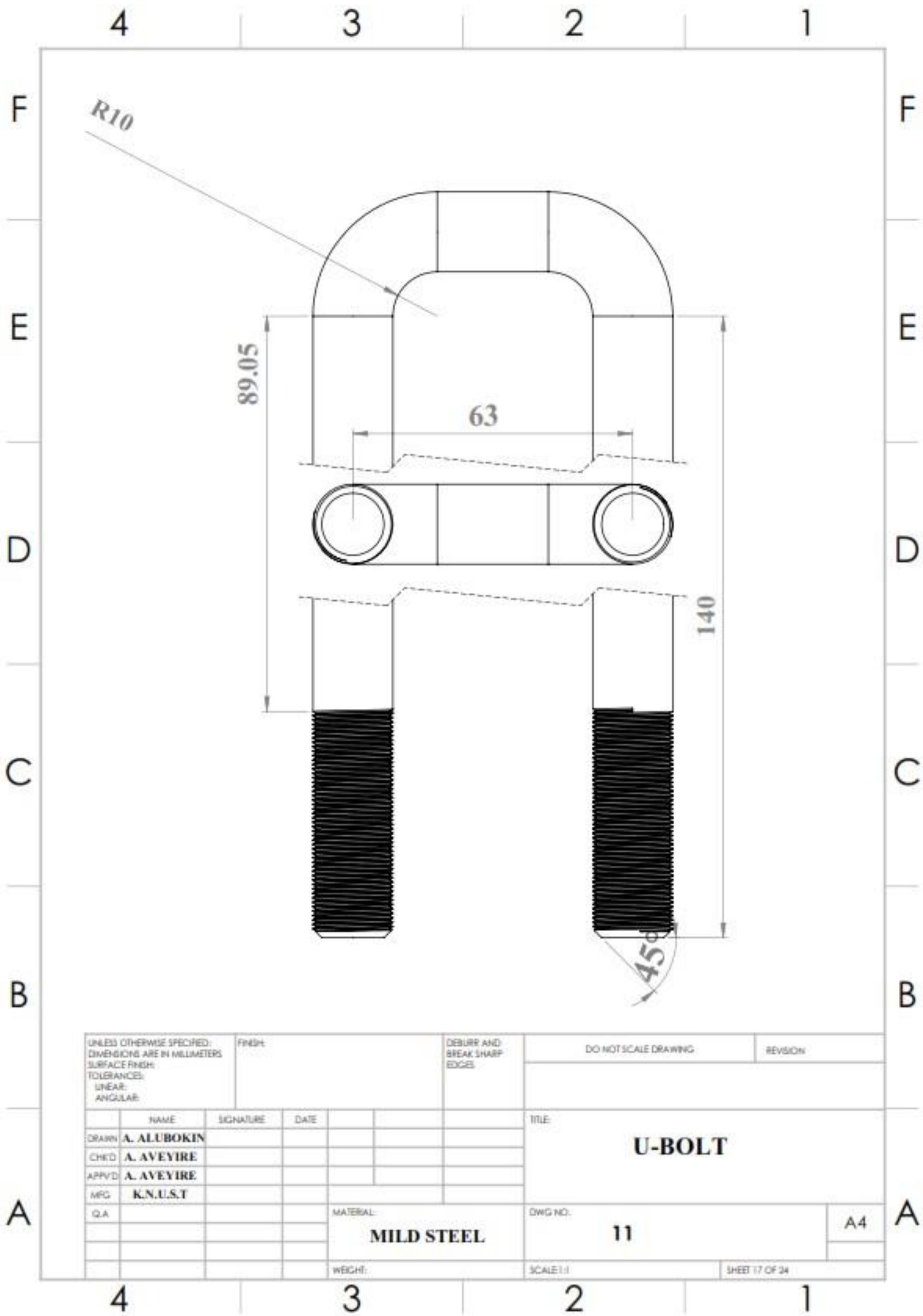
SHEET 13 OF 24



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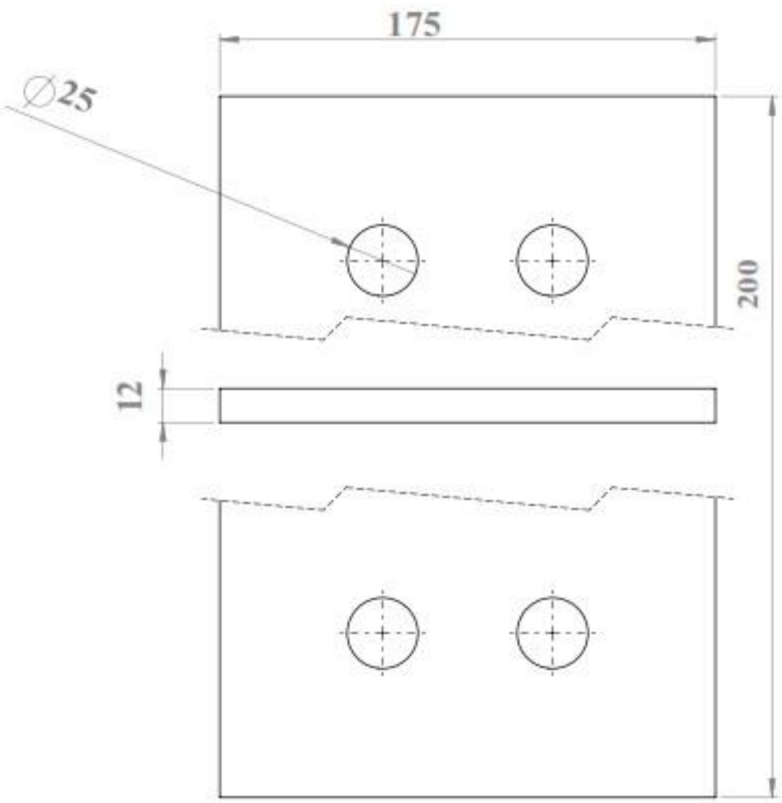
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A. ALUBOKIN
CHK'D A. AVEYIRE
APPV'D A. AVEYIRE
MFG K.N.U.S.T
Q.A
MATERIAL:
MILD STEEL
WEIGHT:
TITLE:
U-BOLT
DWG NO.
11
A4
SCALE:1:1
SHEET 17 OF 24



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			REVISION

	NAME	SIGNATURE	DATE
DRAWN	A. ALUBOKIN		
CHK'D	A. AVEYIRE		
APPV'D	A. AVEYIRE		
MFG	K.N.U.S.T		
Q.A			

TITLE:

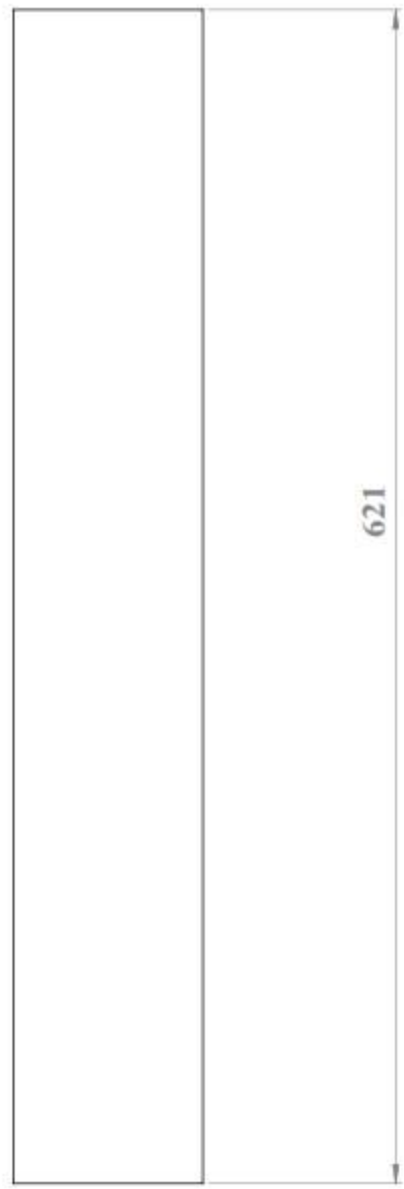
HITCH FRAME HOIST

MATERIAL: **MILD STEEL**

DWG NO. **10** A4

WEIGHT:

SCALE:1:2 SHEET 16 OF 24



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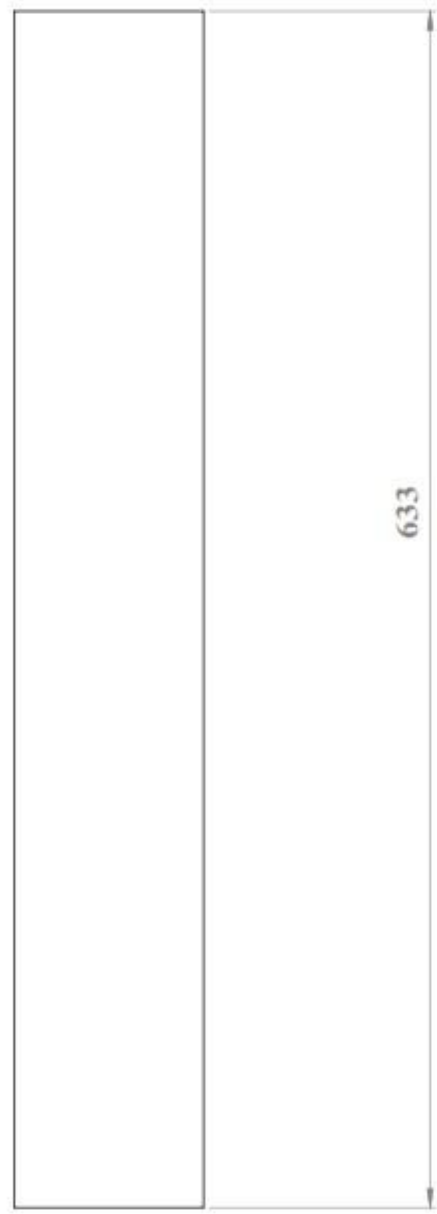
	NAME	SIGNATURE	DATE	TITLE:		
DRAWN	A. ALUBOKIN			HARVESTER BASE MIDDLE LEG		
CHK'D	A. AVEYIRE					
APPV'D	A. AVEYIRE					
MFG	K.N.U.S.T					
Q.A				MATERIAL: MILD STEEL	DWG NO. 9	A4
				WEIGHT:	SCALE:1:5	SHEET 15 OF 24



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	NAME	SIGNATURE	DATE
DRAWN	A. ALUBOKIN		
CHK'D	A. AVEYIRE		
APPV'D	A. AVEYIRE		
MFG	K.N.U.S.T		
Q.A			

TITLE:

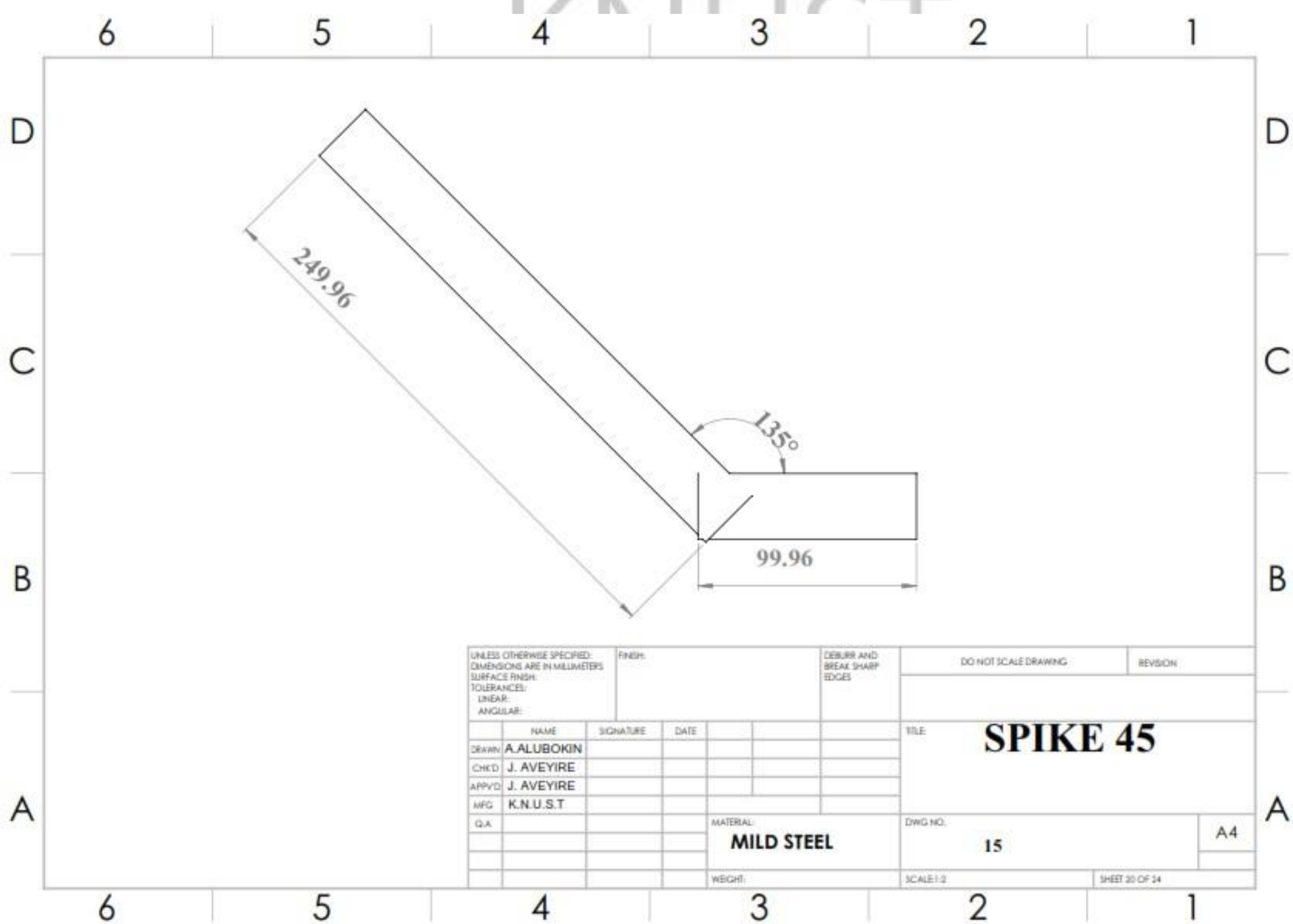
HARVESTER BASE OUTER LEG

MATERIAL: **MILD STEEL**

DWG NO. **8** A4

WEIGHT:

SCALE:1:3 SHEET 14 OF 24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TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A.ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
TITLE:
SPIKE 45
MATERIAL:
MILD STEEL
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15
A4
WEIGHT:
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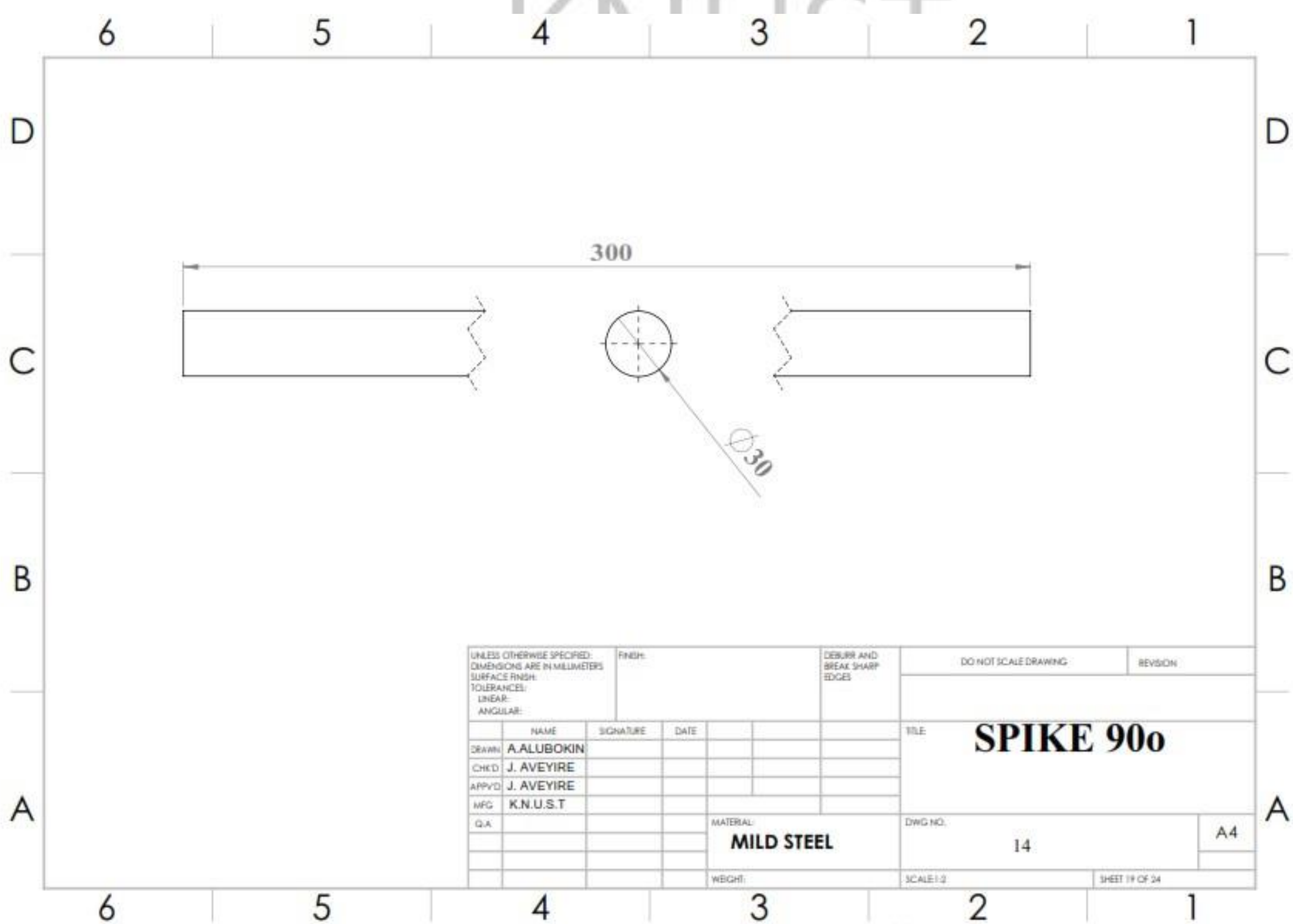
SHEET 20 OF 24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B
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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A.ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
TITLE:
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MATERIAL:
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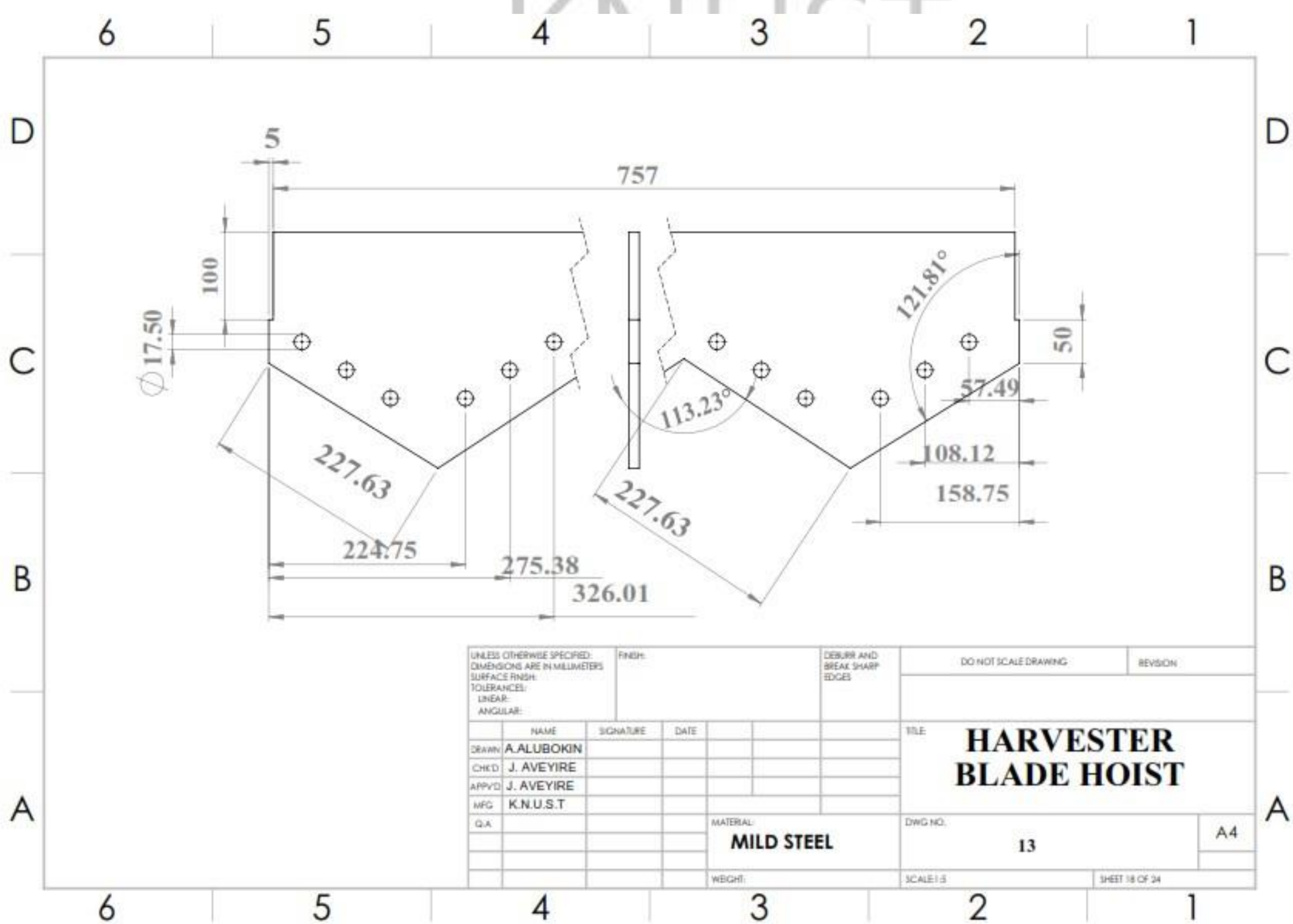
DWG NO.
14
A4
WEIGHT:
SCALE:1:2
SHEET 19 OF 24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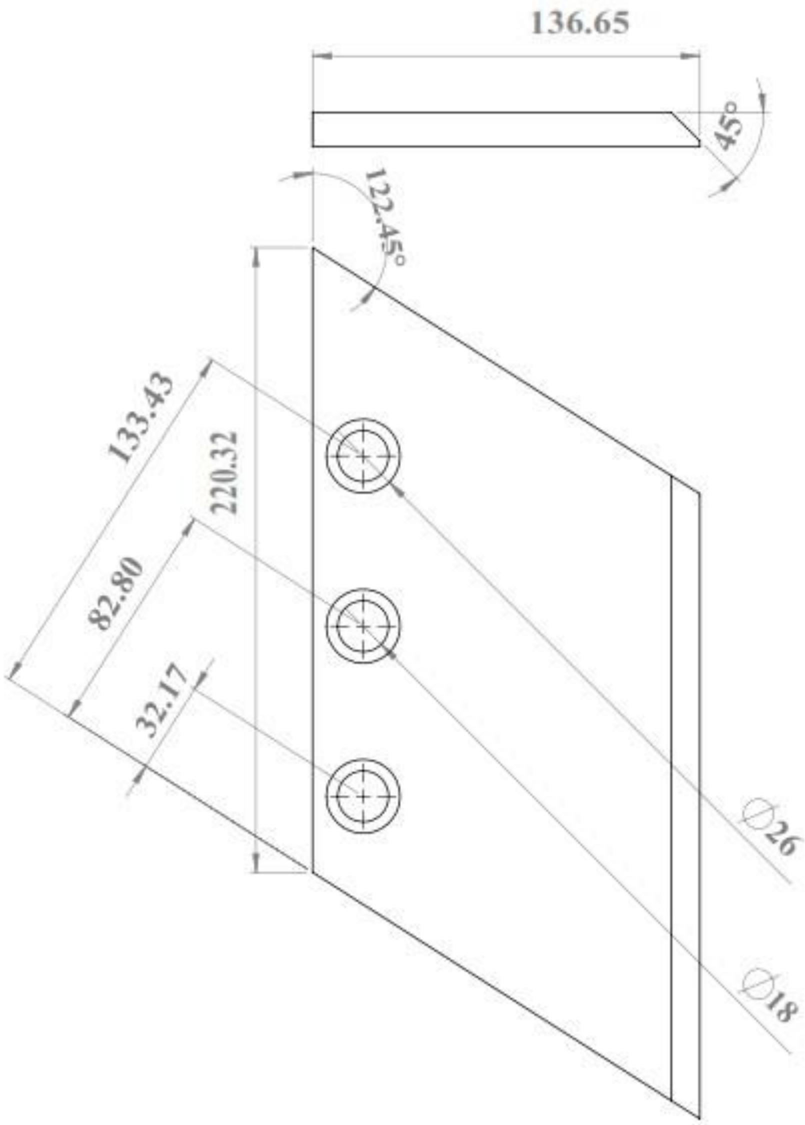
108.12
158.75
227.63
227.63
224.75
275.38
326.01
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN A.ALUBOKIN
CHK'D J. AVEYIRE
APPV'D J. AVEYIRE
MFG K.N.U.S.T
Q.A
TITLE:
HARVESTER BLADE HOIST
MATERIAL:
MILD STEEL
DWG NO.
13
A4
WEIGHT:
SCALE:1:5
SHEET 18 OF 24



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DIMENSIONS ARE IN MILLIMETERS
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TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	A. ALUBOKIN		
CHK'D	A. AVEYIRE		
APPV'D	A. AVEYIRE		
MFG	K.N.U.S.T		
Q.A			

TITLE:

HARVESTER BLADE LEFT

MATERIAL: **MILD STEEL**

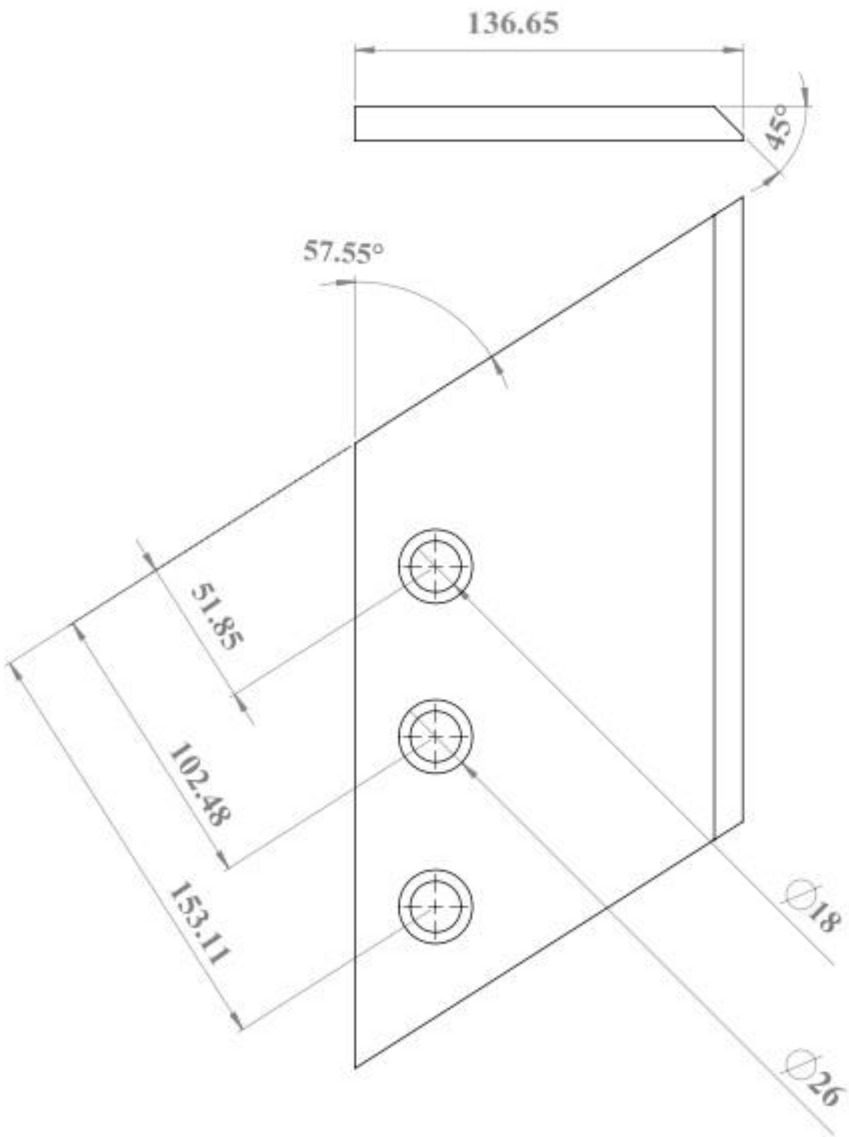
DWG NO. **20**

A4

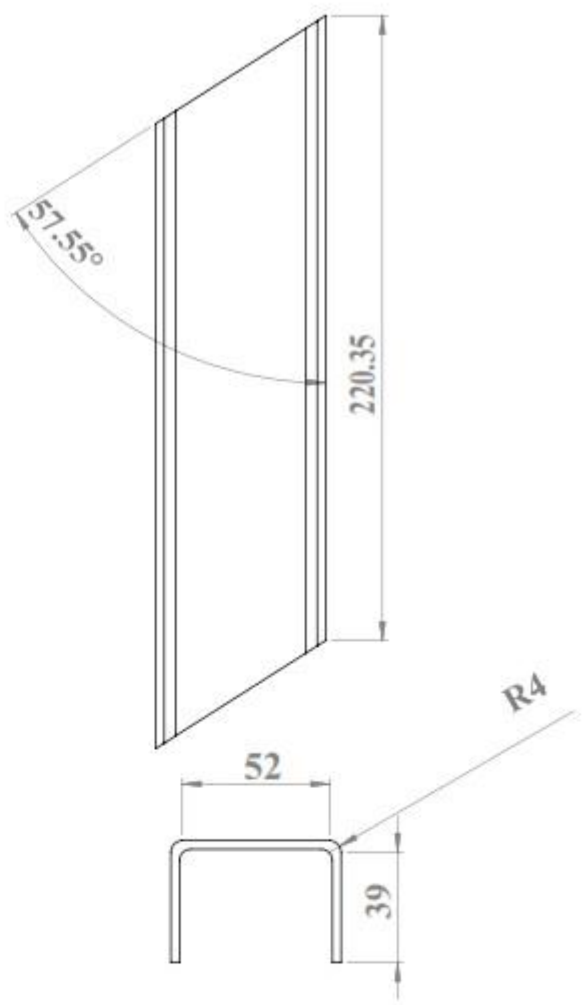
WEIGHT:

SCALE:1:2

SHEET 24 OF 24



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:			DEBURR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING	REVISION	
	NAME	SIGNATURE	DATE		TITLE:		
DRAWN	A. ALUBOKIN				HARVESTER BLADE RIGHT		
CHK'D	A. AVEYIRE						
APPV'D	A. AVEYIRE						
MFG	K.N.U.S.T						
Q.A				MATERIAL: MILD STEEL	DWG NO. 19		A4
				WEIGHT:	SCALE:1:2	SHEET 23 OF 24	



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN	A. ALUBOKIN		
CHK'D	A. AVEYIRE		
APPV'D	A. AVEYIRE		
MFG	K.N.U.S.T		
Q.A			

TITLE:

DOOM LEFT

MATERIAL:

MILD STEEL

DWG NO.

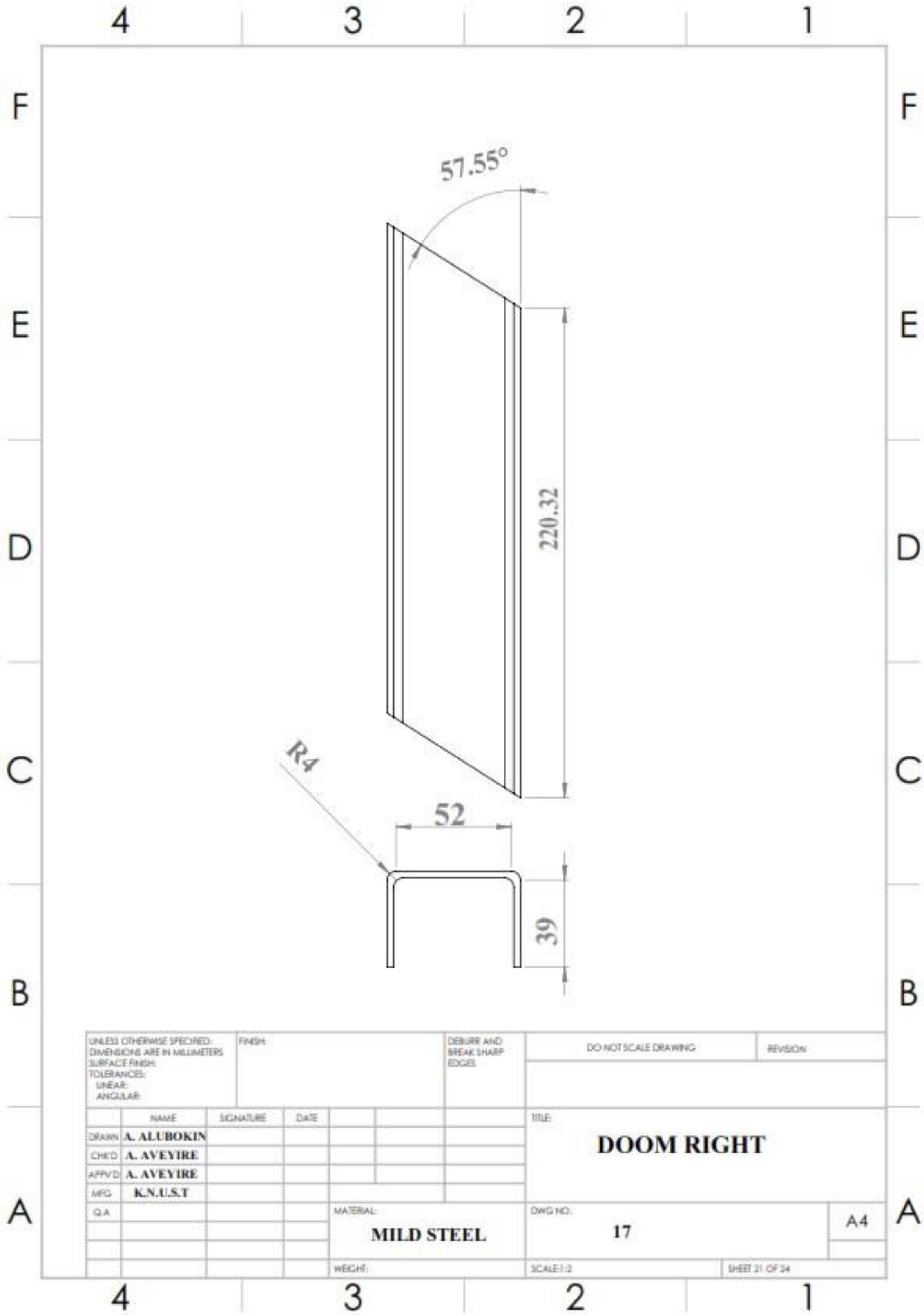
18

A4

WEIGHT:

SCALE:1:2

SHEET 22 OF 24



Appendix 8: Cost of material

Table 8. 8: Bill of quantities

Materials	Total Qnty (length)	Standard Length of Material	Unit Cost (GHȻ)	Qnty required of the Standard (m)	Estimated Cost (GHȻ)
12 mm plate	$0.5m^2$	$2m^2$	1000	0.5	500
3mm plate	$0.2m^2$	$2m^2$	250	0.25	62.5
Flat-bar 10 × 100	2m	6m	450	0.5	225
u-bar 45 x 100	4m	6m	320	0.75	240
16 mm rebar (deformed)	2m	3m	25	1	25
16 round bar	$0.5m^2$	3m	25	0.25	6.25
Grader blade 12 mm	1m	4m	400	0.25	100
Total					1158.75

Other Costs

Workmanship = GhȻ 700.00

Transportation = GhȻ 600.00

Miscellaneous = GhȻ 700.00

Grand Total = GhȻ 3158 .75 Appendix 9: Photographs of tractor-mounted groundnut harvester

Figure 8. 9: Parameters for obtaining moment of inertia about a point of the blade

Figure 8. 10: Hitched tractor mounted groundnut harvester

Figure 8. 11: Harvesting with tractor mounted harvester

Appendix 10: Field layout of experimental design

Figure 8.12 presents the field layout of the experimental design. Each plot is labelled and measures 6 m × 4 m. A space of 10 m is left between plots to allow for easy movement of the tractor. The designations on the Figure 8.12 are explained as follows:

BLK I = Block one

BLK II = Block two

BLK III = Block three

Alphabet	*Treatment*
A	Hand hoe harvesting
B	Cutlass harvesting
C	Groundnut harvester harvesting
D	Hand fork harvesting
E	Hand pulling harvesting

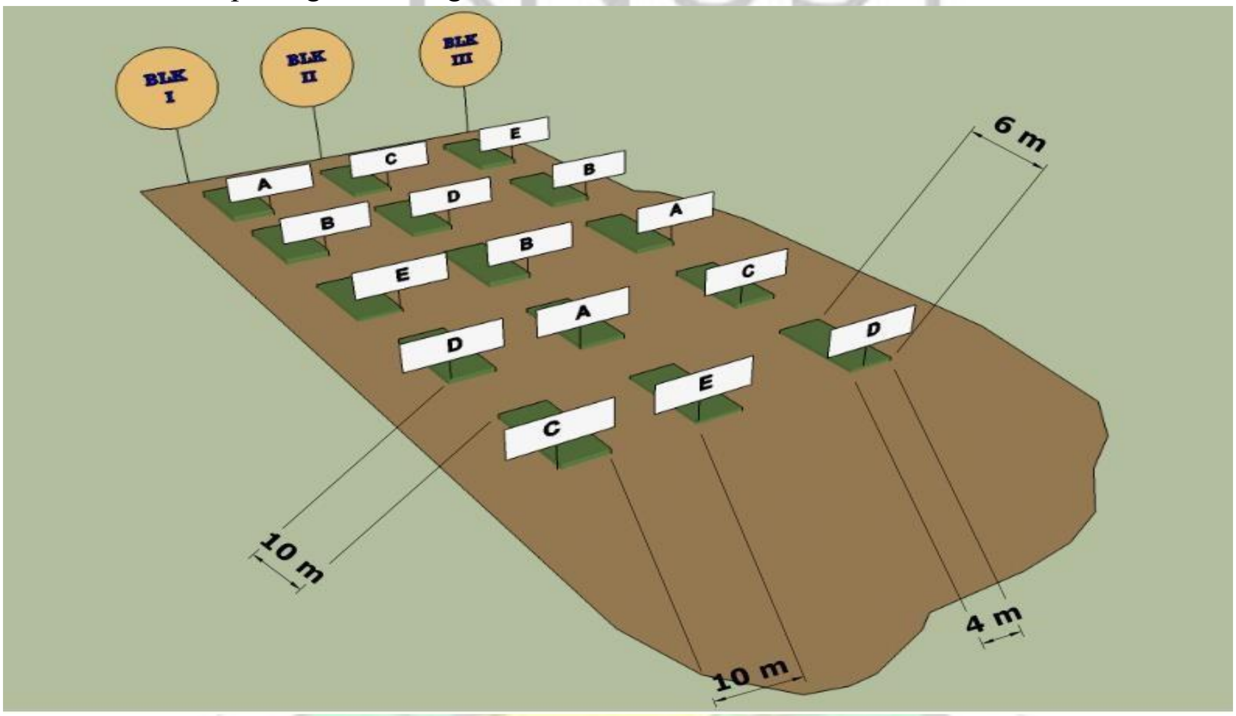


Figure 8. 12:field layout of plots

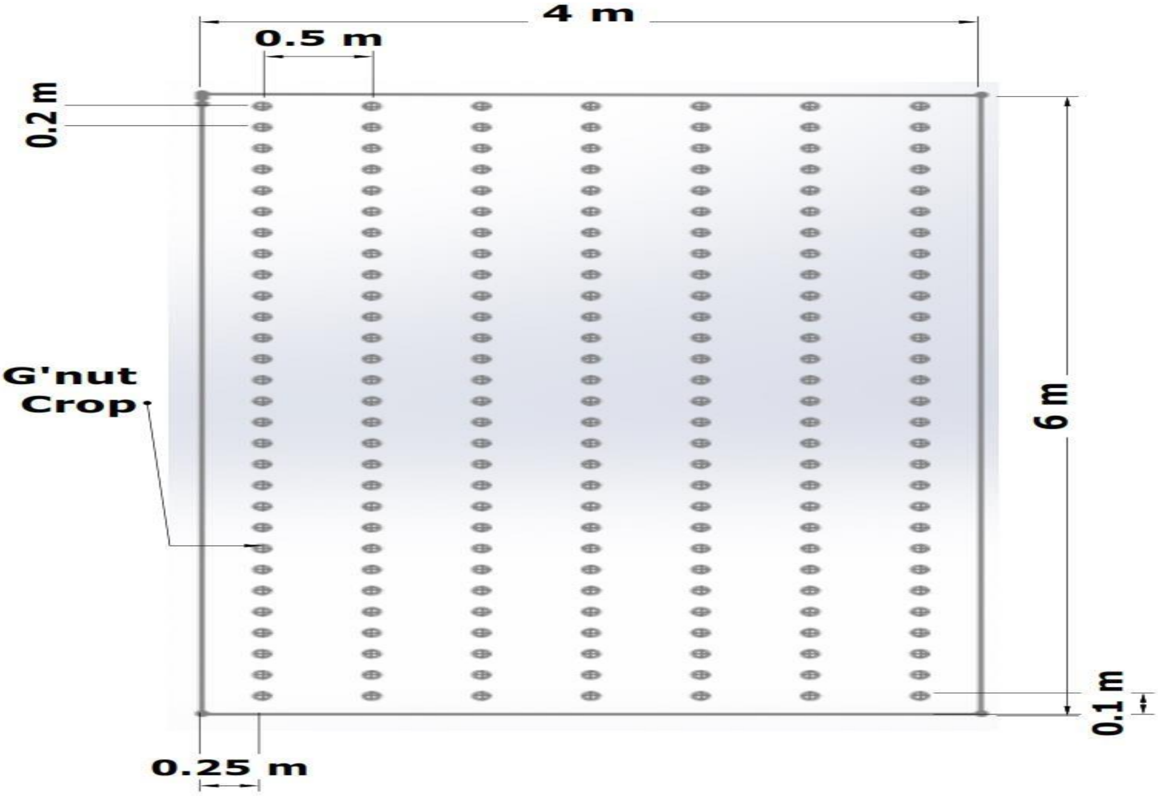


Figure 8. 13: plot layout showing groundnut crops on ridges

Appendix 11: Balanced ANOVA output

ANOVA:

```
Factor     Type    Levels  Values
Block      fixed        3  1, 2, 3
Treatment  random       5  Cutlass, Groundnut Harvester, Hand fork, Hand hoe, Hand
pulling


Analysis of Variance for Vine and pods yield (kg/ha)

Source     DF        SS       MS     F      P
Block       2   3112037  1556019  0.30  0.751
Treatment   4  21040972  5260243  1.01  0.458
Error       8  41841667  5230208
Total      14  65994676


S = 2286.96   R-Sq = 36.60%   R-Sq(adj) = 0.00%


                                Expected Mean
                                Square for Each
                                Term (using
                Variance  Error  unrestricted
   Source      component   term  model)
```

1	Block		3	(3) + Q[1]
2	Treatment	10012	3	(3) + 3 (2)
3	Error	5230208		(3)

Analysis of Variance for Damaged pods collected (%)

Source	DF	SS	MS	F	P
Block	2	0.04662	0.02331	1.20	0.351
Treatment	4	0.39565	0.09891	5.08	0.025
Error	8	0.15576	0.01947		
Total	14	0.59804			

S = 0.139537   R-Sq = 73.95%   R-Sq(adj) = 54.42%

	Source	Variance component	Error term	Expected Mean Square for Each Term (using unrestricted model)
1	Block		3	(3) + Q[1]
2	Treatment	0.02648	3	(3) + 3 (2)
3	Error	0.01947		(3)

Analysis of Variance for Total detached pods (%)

Source	DF	SS	MS	F	P
Block	2	91.26	45.63	0.79	0.488
Treatment	4	1473.80	368.45	6.35	0.013
Error	8	464.42	58.05		
Total	14	2029.48			

S = 7.61920   R-Sq = 77.12%   R-Sq(adj) = 59.95%

	Source	Variance component	Error term	Expected Mean Square for Each Term (using unrestricted model)
1	Block		3	(3) + Q[1]
2	Treatment	103.47	3	(3) + 3 (2)
3	Error	58.05		(3)

Analysis of Variance for Total pod loss(%)

Source	DF	SS	MS	F	P
Block	2	88.79	44.39	0.76	0.500
Treatment	4	1484.48	371.12	6.33	0.013
Error	8	469.05	58.63		
Total	14	2042.31			

S = 7.65706   R-Sq = 77.03%   R-Sq(adj) = 59.81%

	Source	Variance component	Error term	Expected Mean Square for Each Term (using unrestricted model)
1	Block		3	(3) + Q[1]
2	Treatment	104.16	3	(3) + 3 (2)
3	Error	58.63		(3)

Analysis of Variance for 1000-seed weight (g)

Source	DF	SS	MS	F	P
Block	2	2610	1305	0.36	0.708
Treatment	4	15258	3815	1.05	0.438
Error	8	28941	3618		
Total	14	46809			

S = 60.1467   R-Sq = 38.17%   R-Sq(adj) = 0.00%

	Source	Variance component	Error term	Expected Mean Square for Each Term (using unrestricted model)
1	Block		3	(3) + Q[1]
2	Treatment	65.66	3	(3) + 3 (2)
3	Error	3617.63		(3)

Means

Vine and	pods	Total	Damaged			
Treatment	N	pods yield (kg/ha)	collected (%)	detached pods (%)	Total pod loss(%)	1000-seed weight (g)
Cutlass	3	1861.1	0.43805	2.215	2.653	298.60
Groundnut Harvester	3	1833.3	0.19394	25.451	25.645	359.97
Hand fork	3	2402.8	0.00000	0.554	0.554	394.43
Hand hoe	3	4041.7	0.10513	0.000	0.105	341.07
Hand pulling	3	4708.3	0.00000	0.219	0.219	329.17

If:

$$LSD = \sqrt{\frac{2 \times \text{Error MS}}{r}} \times t \text{ error df. @ 5\%}$$

Response Variable	Error MS for treatment(s)	2 x Error MS	r	√ (2 x Error MS/R)	*t* error df. @ 5%	LSD
Damaged pods	0.01947	0.03894	3	0.113929803	2.306	0.26
Pod loss	57.21	114.42	3	6.175759063	2.306	14.24
Detached pod	58.05	116.1	3	6.220932406	2.306	14.35

Damaged pod (%)

Treatment(s)	Means	LSD	Means-LSD	Treatment Means significance*
Cutlass	0.44	0.26	0.18	0.45a
Groundnut Harvester	0.19	0.26	-0.07	0.19ab
Hand hoe	0.11	0.26	-0.16	0.11b
Hand pulling	0	0.26	-0.26	0b
Hand fork	0	0.26	-0.26	0b

Total detached pod (%)

Treatment(s)	Means	LSD	Means-LSD	Treatment Means significance*
Groundnut Harvester	25.46	14.35	25.32	25.46a
Cutlass	2.21	14.35	2.07	2.21b
Hand fork	0.55	14.35	0.41	0.55b
Hand pulling	0.22	14.35	0.08	0.22b
Hand hoe	0	14.35	-0.14	0b

Total Pod loss (%)

Treatment(s)	Means	LSD	Means-LSD	Treatment Means significance*
Groundnut Harvester	25.6451	14.24	11.40	25.6451a

Cutlass	1.2787	14.24	-12.96	1.2787b
Hand fork	0.5537	14.24	-13.69	0.5537b
Hand pulling	0.2192	14.24	-14.02	0.2192b
Hand hoe	0.1051	14.24	-14.14	0.1051b

*Treatment Means followed by the same or share an alphabet are not significantly different at $P \leq 0.05$