DEVELOPMENT OF POWER TILLER OPERATED RICE COMBINE HARVESTER FOR SMALLHOLDER FARMERS IN TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL ENGINEERING OF SOKOINEUNIVERSITY OF AGRICULTURE.MOROGORO, TANZANIA.

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ABSTRACT

This study was conducted to develop a Power Tiller Operated Rice Combine Harvester (PORCH) for small holder farmers in Tanzania. PORCH can be attached to a power tiller during harvesting operation and detached to give the power tiller a room for other operations. The study aimed at designing, construction and testing performance of PORCH prototype.Design specifications and drawings were developed and prototype was constructed.The performance of PORCH prototype was tested in Lower Moshi and compared to manual harvesting. Comparisons made included manpower required (man-h/acre), harvesting capacity (acre/h), grain loss (%), presence of material other than grain (MOG %) in the harvested grain, and harvesting cost. It was foundthat in PORCH harvesting average values of man-h, harvesting capacity, cost, grain loss and MOG were 4.76 h/acre, 0.42 acre/h, TSh.30151/acre, 28.86% and 3.19% respectively. While the average values of man-h, harvesting capacity, cost, grain loss and MOG for manual harvesting were 255.9 h/acre, 0.0039 acre/h, TSh. 181250/acre, 14.84% and 8.3% respectively. Hence PORCH harvesting was better for all performance measures made except grain loss reduction. More grain loss in PORCH harvesting was due to leakagesin some of PORCH functional elements. Grain loss can be reduced by avoiding leakages in PORCH functional elements. It was recommended in future that modifications should be done so as to alleviateshortcomings in PORCH functional elements.

DECLARATION

I, **Godfrey Mwinama**, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that has neitherbeen submitted nor being concurrently submitted in any other institution.

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The above declaration is confirmed by

________________________ ________________________

Eng. Prof. S. M. Mpanduji Date

(Supervisor)

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DEDICATIONS

This dissertation is dedicated to my beloved daughters Gladness Lulu and Glory Christabela, my wife Dorika, and my mother Christabela because of their continuous encouragement towards my success.

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LIST OF ABBREVIATIONS

AGITF	Agricultural Inputs Trust Fund
CAMARTEC	Centre for Agricultural Mechanization and Rural Technology
COSTECH	Commission for Science and Technology
CRBD	Completely Randomised Block Design
CV	Coefficient of variation
DADP	District Agriculture Development Plan
DASIP	District Agriculture Sector Investment Project
DAT	Draught Animal Technology
EPT	Engine Power Technology
FAO	Food and Agriculture Organization
GRiSP	Global Rice Science Partnership
HTT	Hand Tool Technology
IRRI	International Rice Research Institute
ISO	Industrial Support Organizations
KKIGR	Kilimo Kwanza Initiative for Green Revolution
MAFSC	Ministry of Agriculture, Food Security and Cooperative
MFEA	Ministry of Finance and Economic Affairs
MIT	Ministry of Industry and Trade
MOG	Materials other than grain
MSTHE	Ministry of Science, Technology and Higher Education
PORCH	Power Tiller Operated Rice Combine Harvester
RLDC	Rural Livelihood Development Company
RNAM	Regional Network for Agricultural Machinery
SIDO	Small Industries Development Organization

SME	Small and Medium Enterprise
SMMF	Small and Medium Manufacturing Firm
SSA	Sub Sahara Africa
TAMS	Tanzania Agricultural Mechanization Strategy
TAMU	Texas A&M University
TEMDO	Tanzania Engineering and Manufacturing Development Organization
TIRDO	Tanzania Industrial Research Development Organization
VST	VelooMudaliar's sonThiruvengadaswamy

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Rice (*Oryzasativa*L.) is used by about half of the world's population as main food crop (Zakayo, 2003). Tanzania is the second largest rice producer after Madagascar in Eastern and Southern Africa(Kessy, 2009) where about 90% of rice is cultivated in small holdings of 0.5 to 2 ha (Deckers*et al*., 2003).The average riceyield is 1.5 – 2.1 ton/ha in rain fed fields and up to 6 tons/ha in irrigated fields (Kessy, 2009). For the period of 10 years (1996 to 2006), the averageacreage of rice field per year was 474000 ha with an average yield of 769 048 tons per year (Kessy, 2009).

In South–Eastern Tanzania, rice is the third mostimportant food crop after maize (*Zea mays* L.) and cassava (*Manihotesculenta*Crantz). In rain fed fields, rice is planted at the end of December or early January andharvested in between the end of May andthe end of June coinciding with the beginning of dry season. In irrigated fields transplanting can be as late as March (Deckers*et al*., 2003).

Among major constraints to rice production in Sub-Sahara Africa (SSA) is labour shortages at critical times in all rice field operations (GRiSP, 2011 and IRRI, 2009). Harvesting and transporting require60-80 person days/ha (GRiSP, 2011).Rice harvesting in Tanzania is mostly done manually, through threshing; this is the hardest work in rice cultivation(Kato, 2007).Rice quality can be affected by grain moisture content, field rewetting of grain, severe threshing impacts and excessive foreign matterin the rice (Huitink and Siebenmorgen, 1996). The current status of rice growers in Tanzania needs to be improved so as to have toilage and drudgery free operations such as land preparation, planting, transplanting, weeding, pesticide application, harvesting, threshing and grain cleaning. This raises the need of several machines including power tillers which apart from doing several operations as they are imported, some locally made implements and equipment can be attached to them for specific agricultural operations.

In Tanzania, the number of power tillers has kept on increasing since 2005. According to MAFSC (2006), theTanzania governmentpurchased230 power-tillers for demonstration in 2005and about 100 power-tillers are estimated to have been supplied by private sector annually since 2005.Some power tillers were imported in Tanzania under different government programs including Agricultural Inputs Trust Fund (AGITF),District Agriculture Development Plans(DADPs)and District Agriculture Sector Investment Project (DASIP). The total number of power tillers imported by these programs in the year 2009/10 was 2647 (Lyimo, 2011).

Further, an increase of power tillers in Tanzania has been attributed to “Kilimo Kwanza” (Agriculture first) Initiative;this is thenational agenda of transforming agriculture through the introduction of new and innovative technologies so as to increasefoodproduction and agricultural exports.“Kilimo Kwanza initiative” for green revolution (KKIGR) has strengthened agricultural equipment basket fund for small scale farmers (Policy Forum, 2011).

The use of power tillers by smallholder farmers in Tanzania can be more economical than the use ofconventional tractors because of the price advantage. This is because power tillers are suitable in small fields that are many in Tanzania and they are cheap in price as compared to conventional tractors.Power-tillers are very useful for rotavation and crop haulage in rice fields. However, in places like Mikese village in Morogoro, power-tillers are also used for haulage of non-agricultural goods especially burnt bricks from brick making sites to construction sites.

Thus, with proper mechanization,power tillers can beused for many other agriculturalactivities such as grain milling, grain threshing, boom spraying, seed drilling and crop harvesting. More exploration of the use of available power tillers in Tanzania relies much on innovations by engineers, technologists and other stakeholders who can be able to identify problemsand thereby produce some tools to solvethe problems.According to MIT (2003), introduction of technology and innovation into production system are the basis for economic competitiveness.

From early ages humans shaped materials and used them as working toolsin carrying out different tasks on earth. Tool making is one of the thingsthat differentiate human beings from other animals. However, people in developing countries of Africa have lost the art of tool making (Makungu, 2010). Despite its advantages, agriculture in Africa has been undervalued due to reliance on poor agricultural technologies such as a hand hoe and a sickle (Odigboh, 2000). It is argued further (Odigboh, 2000) that agriculture in developing countries remains an industry of inherent toilage, poverty and indignity, a world of drudgery for losers. This is supported by Olomi (2009) who found out that most of the people in Tanzania become engaged in agricultureafterfailing to perform other tasks in the formal employment sector.

1.2 Problem statement and justification

In Tanzania, there are more than 3000 power tillers whichhave not yet been fully utilized in agricultural production, because they are operated within a few months of the year especially for paddy production in small scale irrigation schemes (Lyimo, 2011). This means that power tillers during off-season remain practically idle. If this situation continuesunabated,ownership of power tillers would become unsustainable and the efforts geared towardsrevolutionizing agriculture would be undermined. Power tillers could operate more economically if used for other operations staggered throughout the year. One such operation is rice harvesting whichis a labour intensive activity. Therefore, to achieve thisthere is a need of developing appropriate rice combine harvester that will be powered by power tillers.

Available rice combine harvesters (self-propelled combine harvesters, mini combine harvesters and riding-tractor pull-type combine harvesters) are to, a great extent, not quite appropriate technologies to a Tanzanian small scale farmer due to limitations in field sizes, poor manoeuvrabilityas a result of poor trucks in rural farm areas and poor technical knowhow (the software behind them) of operating and maintaining the machines. Also available reaper binders could only cut and bind rice crop after which threshing and winnowing had to be done either by stationary thresher or manually, which alsoinvolve limited technical knowhow in operating and maintaining them; and they are labour intensive because they involve manual collecting and feeding bound crop to the stationary thresher or threshing it manually. Therefore, this study will add value onthe development of appropriate combine harvester as an attachment to a power tiller for use in Tanzania and in other countries with similar conditions.This would lead to diversification of the use of available power tillers.

Development of a power tiller operated rice combine harvester (PORCH) was deemed necessary for a number of reasons; these include reduction of toilage and drudgery during rice harvesting hence changing farmers’ status; improving quality of rice due to timely harvesting; attracting youths and women into taking up rice production; supplementing agricultural labour shortages during harvesting period; and appropriate mechanization for KKIGR in Tanzania.

1.3 Objectives

1.3.1 Overall objective

The study aims at developing a power tiller operated rice combine harvesterfor small holder farmers in Tanzania.

1.3.2 Specific objectives

The specific objectives are:

i. To design a power tiller operated rice combine harvester for small holder farmers in Tanzania

ii. To manufacture the power tiller operated rice combine harvester prototype

iii. To carryout field performance test of the developed power tiller operated rice combine harvester prototypeand compareit to manual rice harvesting.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice Production in Tanzania

Rice production in Tanzania covers about 18% of Tanzania's cultivated land. Rice under irrigated land is about 29% of the total land for rice cultivation with most of it being in traditional irrigation schemes of small village level (RLDC, 2011). Rice production is among the major sources of employment in Tanzania. People in the rural areas where rice production is the predominant activity grow rice. In Tanzania rice harvested area expanded from 490000ha in 1998 to665000 ha in 2007(MAFSC, 2009). However, there haven't been manychanges in the rice mechanization technology such as harvesting as most of the peasants still use hand tools (MAFSC, 2006).

FAO (2010 a)reported to have recorded harvests in rice production of 1.4 million tons (910,000 tons milled basis) in 2010 in Tanzania.Rice production is projected to increase further in Tanzania in a few years to come because of various effortsmade by the Tanzanian government with the support from the US and Korean governments. The US government planned to support irrigation schemes of over 2000 ha of land and to upgrade irrigation facilities in over 52000 ha soas toraise the output of key staples including rice up to 25%.The government of the Republic of Korea is planning to develop irrigation schemes covering 10000 ha of rice fields in lower Rufiji area.

There are number of challenges encountered in rice production in Tanzania. Some of challenges facing rice production in Tanzania are as listed below:

i. Lack of small post harvestequipment (FAO, 2000 and MAFSC, 2006);
ii. High cost of importing equipment as opposed tohaving them locally produced in a mass scale(Bell *et al.*, 2003);
iii. Postharvest losses (Alli*et al.*, 2010,GRiSP,2011, IRRI, 2009 and Lyimo, 2011);
iv. Lack of agricultural technology, equipment or basic inputs such as seeds, fertilizers and credits (Policy forum 2009);
v. Rural to urban migration (FAO, 2008 and MAFS, 2004);
vi. Use of long maturing traditional varieties by most rice farmers (RLDC, 2011);
vii. Irregular rainfall patterns and incidences of pestsand diseases (RLDC, 2011);
viii. Past donors criticism on agricultural mechanization in developing countries because mechanizationwas blamed for exacerbating rural unemployment(Rijk, 1989); and
ix. High running and maintenance costs in transforming mechanization (RLDC, 2011).

2.2 Agricultural Mechanization

Agricultural mechanization is the application of tools, machines and equipment in three levels of farm power, namely,manual power or hand-tool technology (HTT), draftanimal technology (DAT),and motorized power or engine-powered technology (EPT). Inputs for agricultural mechanization include tools, implements and powered machineryfor agricultural land preparation, crop production, harvesting, and preparation for storage, storage and on farm processing. Agricultural mechanization provides the basis on how to manufacture, distribute, repair, maintain, manage and use agricultural tools, implement, and machines.

To mechanise is to use machines to achieve an operationmindless of how simple or complex the machine is.Thepurposes for mechanization include increasinglabour productivityleading to alleviation oflabour shortages,increasingland productivity, decreasingthe cost of production,and improvingtimeliness and efficiency of farm operations. Other purposes include accomplishing the tasks that are difficult to perform without mechanical aid as well asimproving the qualityand value of work. Mechanization is alsoused inproductionand processing of products,provision of employment (entrepreneurship) and sustainable rural livelihood, provision of agricultural-led industrialization and markets for rural economic growth,andreducing toilage and drudgery in farming activities thereby enhancing life style (FAO, 2008).

According to Odigboh (2000), scientifically a farmer using HTT can cultivate only about one hectare of land annuallydue to failure to meet timely field operations. This limits production and earning capacity offamilies.

There are many work animals for DAT. Some include donkeys, bulls, camels and elephants. DAT is affected by such factorsas characteristics and working abilities of some species, low energy potential of some species delimited by body weight, environmental stresses andage–health–nourishment status. Normally a team of animals such as cows, horses and donkeys can provide a sustained effort at a normal speed of 0.6–0.8 m/s only for about 2–3 hours per day (Odigboh, 2000).

EPT uses implements, machines and equipment normally poweredby engines or motors.Odigboh (2000) observed that the common and best known power source in agriculture today is the tractor, which comes in a wide range of types, makes, sizes, power ratings and capabilities that are easy for an expert to select and match a system that is appropriate to a specific situation.

Appropriate mechanization refers to the level of mechanization and the manner in which it is used ina specific situation. Determination of “Appropriateness” should consider technical, economical and social characteristics of a situation.

According to FAO (2008), 30–40% of agricultural produce in Africa is lost due to poor post-harvest handling, storage, and processing methods. The low level of engineering technology inputs in agriculture isone of the main constraints hindering modernization of agriculture and food production system in Africa (FAO, 2008 and Lyimo, 2011).HTT and DAT have been used for a long time in Africabut have failed to eradicate poverty and starvation. As a result,the agricultural sector has become less attractive to many young people in Africa (Odigboh,2000).Poverty in Africa has also been caused by overdependence on inappropriate foreign imported technologies (Odigboh, 2000). Most of the imported agricultural machineries have been abandoned because of inappropriate design, lack of spare parts or costly maintenance (GRiSP, 2011). Lack of suitable machinery packages for main agricultural operations and general poor technical knowhow are among the factors constraining development of mechanization in Tanzania (Lyimo, 2011).

The use of appropriate level of engine power agricultural mechanization technology, through the establishment of local manufacture of needed machines and equipment can reduceboth poverty and starvation (Odigboh, 2000).MFEA (2010) advocates the strengthening of investment in agricultural mechanization as one of the tools for growth and poverty reduction in Tanzania. According to Olomi (2009),manufacturing is one of underutilised opportunities in Tanzania. This is because among the Small and Medium Enterprises (SMEs) in Tanzania, manufacturingtake the smallest part as opposed to other SMEs firms.

According to (MSTHE, 1996),agricultural mechanization programs should consider crops, ecosystem of the respective area, and capacity to produce and maintain machines to be used as essential components of the programs.MSTHE (1996) puts further emphasis on the intensification of research and development of local prototypes for mechanization, and the use of appropriate technologies in respect to the size of operation and natural resources available. According to RLDC (2011), mechanization of rice is thoughtto beone of the key areas for intervention in the transformation of the rice sector in Tanzania.

2.3 Power Tillers

A power tiller is a single axletractor sometimes called a walking tractor, a walk behind tractor or two wheeled tractor. The transmission of the power tiller usually consists of a variable speed V-belt drive from the engine. It has a gear-box which is normally chain driven. The gear box drives the wheels through final transmissions.Power losses in the mechanical transmission systems of power tillers are usually less than 10% (Macmillan, 2002). One of power tiller manufactures (VST) addressed that lifeof a power tiller is approximately 10years (VST Tillers Tractors Ltd, 2011). Some parts of a power tiller are shown in Fig.1 and Fig. 2.

Power tiller can increase cropping intensity, yields and save cost in operations such as plowing. Power tillers have increased agricultural production in different countries including Nepal (Dhakal*et al*., 2001) and India (Singh, 2002). A power-tiller has different uses including haulage and land preparation activities such as disc plowing, disc harrowing, mould board plowing and rotavation. Power-tillers can also be used for zero-tillage seed drilling, boom spraying and crop gathering when attached with a cutter-bar. In stationary state, a power-tiller can be used to run different machines including water pump, maize shellers. In a nut shell, a power-tiller as a source of farm power can be used to perform different field operations depending on the need and innovations by different stakeholders including engineers and technologists.

Figure 1: A power tiller with a trailer (Source: CAMARTEC 2010)

1	Supporter	7	V – belt	13	Trailer
2	Bamper	8	Clutch	14	Steering hand grip
3	Engine	9	Handle bar frame	15	Wheel rim
4	Head lamp	10	Speed changing lever	16	Tyre
5	Flywheel	11	Clutch brake handle	17	Chasis frame
6	Exhaust pipe	12	Operator seat		

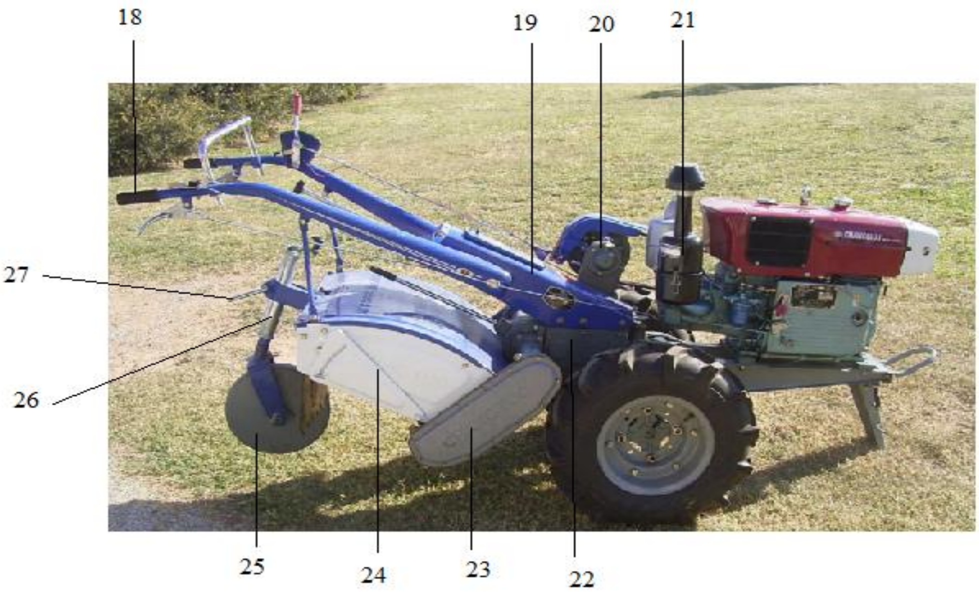

Figure 2: A power tiller with a rotavator (Source: Esdaile, 2010)

18	Handlebar plastic sleeve	23	Rotavator transmission box
19	Hood	24	Rotavator
20	Transmission box	25	Tail wheel
21	Air cleaner	26	Tail wheel sleeve
22	Main drive gearbox	27	Clamping handle

2.4 Combine Harvesters

A combine harvester is a combination of a harvesting machine and thresher as a single unit. The functions of grain combine harvester include harvesting, threshing and cleaning grains in one operation through a number of processes done by its functional elements. Basing on the source of power, combines can be classified as pull-type or self propelled. Basing on how the cut materials are fed into the threshing unit, combines can be classified as either straight through or platform type. Currently, some platform combines make use of axial flow threshers designed by International Rice Research Institute (IRRI) instead of the conventional combine threshers. Axial flow threshers have the advantage of low threshing damage and the possibility of operating without threshing adjustments

(Huitinkand Siebenmorgen, 1996). Basing on how the crop is gathered,a combine harvester can be classified as a cutter-bar header or stripper headers combine harvester.

According to Smith (1976), a pull-type combine harvester is drawn by a tractor and driven by either a Power Take Off (PTO), for small size combine harvesters of cutting width of 1.2–2.4 m, or the one constructed with a separate engine for large size combine harvesters having 3–6 m cutting width.A combine harvester has three or four wheels. Advantages of self propelled combine harvesters include serving the tractor from busy time, their ability to go straight into the crop without any opening out, they can harvest in the most convenient directions, they are easy to transport from field to field and on the roads, and they have the ability to negotiate sharp turns. A combine cutter head can be tilted to cut on slopes of up to 55^{o}, while keeping threshing, separating and cleaning units level (Smith, 1976).A straight through combine is the one in which the cut material is fed directly into the cylinder without any cross–conveying. For such an arrangement, the length of the threshing cylinder and width of the separating unit are nearly as great as the width of the cut (Bainer*et al.*, 1965). Platform combines have platform–type headers. Platform trailed combines need header platforms with cross–conveyor when the width of cut is greater than about 1.8–2.1 m because the length of cylinder required to give a straight-through arrangement would be impractical (Bainer*et al.*, 1965).

Rice combine harvesters are extremely efficient. However, they leave too much grain when improperly operated,especially when operating speed is too high or when soil moisture condition of the field is wet enough to cause slip (speed reduction) of the combine (TAMU 2001). The most economical speed for harvesting rice is about 3.22 km/h(0.894 m/s) at which the average grain loss is about 5.4 %(Malik *et al.*, 1990).A combine harvester requires good understanding of its adjustments for proper functioning; otherwise grain loss and grain damage may occur (Malik *et al*., 1990). If threshing cylinder is adjusted to higher speeds, more grains will be damaged; and if the speeds are too low more straw will pass with unthreshed grains. The recommended thresher speed for rice is around 600-720 rpm for 800 mm stripping drum (Chimchana*et al*., 2008).

2.4.1 Functional elements of a combine harvester

Some functional elements of combine harvester are as shown in Fig. 3.

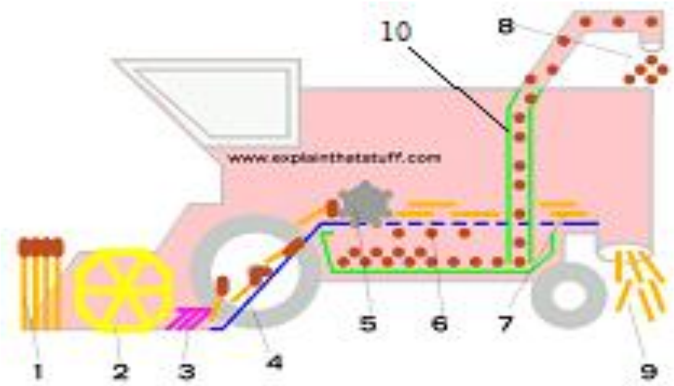

Figure 3: Functional elements of combine (Source: Explanthatstuff, 2008).

1	Header	4	Spinning auger	7	Straw walkers	10	Unloader
2	Pick up real	5	Threshing drum	8	Grains		
3	Cutter bar	6	Sieves	9	Straws outlet		

Header is used for crop gathering. There are two types of headers commonly in use for rice harvesting, namely cutter-bar header and stripper header.

2.4.2 Cutter-bar header combine

Header is made with a sharp pair of pincers at either end used for gathering crops at the front. Pickup reel, cutter-bar and spinning auger are sometimes classified as parts of the header.A pickup reel pushes the crops down toward the cutter bar. The reel has horizontal bars called bats and vertical teeth or tines to grip the plant stalks. A cutter-bar cuts off crops at their base by repeating opening and closing of teeth (mowing fingers). Spinning auger is located behind the cutter-bar to feed the cut crops at a chain and flight conveyor which conveys it up tobe threshed and cleaned. Sieves are used for sieving the threshed grains and making them fall into a collecting tank below it. Straw walkers are conveyors that move the chaff towards the back of the machine anddrop the grains into the tank. Unloader is an elevator used to unload grain from the combine.

2.4.3 Stripper header combine

Stripper harvesting involves stripping the grain from astanding cropwithout cutting the whole plant. Fig. 4 shows the stripping action of Silsoe stripping device which rotates upwards so as to strip the grain heads from crops such as rice. Fig.5 shows a stripper gatherer harvesting in which different stripping devices have been connected to form stripping drum.A stripper header rotating upwardscan replace the combine cutter-bar (Kalsirisilp and Singh, 2001).Bautista and Javier (2005) foundthat the stripped materials were 90-97% already threshed. Stripping offers less labour than the reaper and sustains lessgrain loss than is the case with manual or reaper systems because the grains are handled by the machine without leaving them in the field (Bautista and Javier, 2005).The baffle behind the rotor prevents crop re-entry inside the rotor and the nose determines the position of the crop during harvesting. A stripper header reducessignificantly the amount of straw to be handled in the machinehence increases field capacity, reduces power requirement, reduces tear and wear of machinery, and decreases fuel usage. Furthermore, the machine operateswithout pickup real.This uncomplicated design simplifieslocal manufacturing.Kalsirisilp and Singh (2001) found a total grain loss of 4%in stripper header combine in the standing crop condition and of 5.6 % in the lodged crop conditionwhile that of the cutter bar header combine was at an average of 4.8%.Huitink and Siebenmorgen (1996) found that the harvest loss of the combine harvester increases with harvesting speed; and the optimal thresher speed depends on the moisture content, volume of the materials entering the combine and weeds.Highermoisture contents and higher volume of harvested materials demand higher thresher speeds. Huitink and Siebenmorgen (1996) recommend stripper rotor speeds of 400-600 rpm because excessive speeds add flag leaves to the kernel and inadequate speed leaves rice in the field. They also recommend a thresher speed of 850-1000 rpm for minimum grain loss.With a stripper header combine, early morning and late evening harvesting are possible because of little stalk entering the combine.

Figure 4: Stripping action of Silsoe stripping device (Source: Horio, 2012)

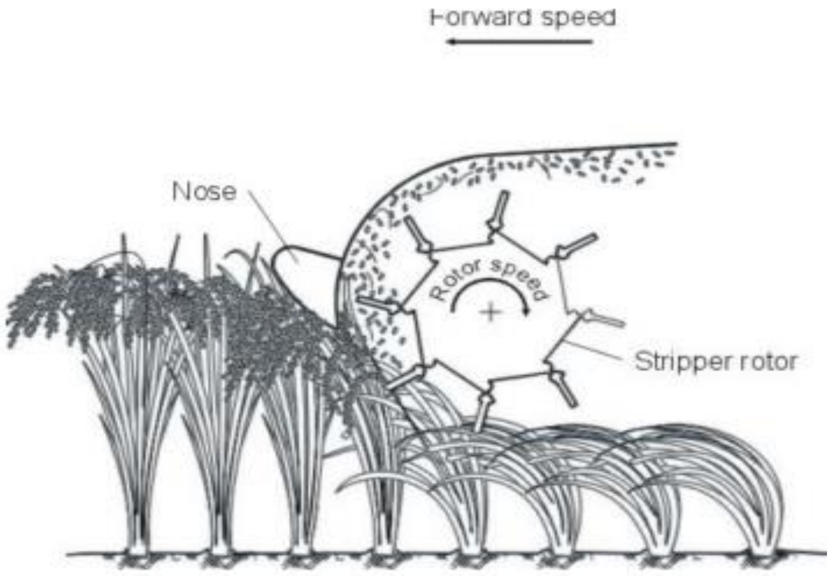

Figure 5: Stripper gathererharvesting (Source: Bautistaand Javier, 2005)

2.5 Some Design Parameters for aCombine Harvester

Parts of a combine harvester that are required to be designed include cutting or stripping mechanism, conveyors , threshers, grain cleaners and means to propel the combine. The data suggested by Bainer*et al*. (1965) include theheight of the cut ranging from 3.8 cm to 90cm,cutting speedof 400–450 rpm,and reel peripheral speed of 25–50% greater than the machine forward speed. The height of the reel should be such that the bottom edges of the slats, at the lowest point of the travel, are a little below the lowest heads of the uncut grain and adjustable.

Kalsirisilp and Singh (2001) recommendthe use of screw conveyor as a better option as compared to elevatorchain for stripped rice. An auger consists of a tube within which rotates a shaft carrying an Archimedean screw (helix) or scroll of continuous metal flight. If the inclination is greater than 15^o, augers with circular cross-section should be used.According to Lazaro (2010), the following are the formulae for calculating the design parameters for augers:

2.5.1 Capacity of horizontal auger (m^3/min)

If C=capacity (m^3/min); D=outside diameter of flight strip (m); d=inside diameter of flight (m); P=pitch (m); n=rotational speed (rpm) then the capacity of the horizontal screw conveyor can be calculate by using equation 1.

$$C = \frac{\pi}{4}(D^2 - d^2)Pn \qquad \text{.......(1)}$$

2.5.2 Auger capacity (ton/h)

If C = Fill factor then equation 2 below can be used to calculate the output of the conveyor in tons per hour.

$$\text{Tons/hour} = C \times (m^3/\text{min}) \times (\text{tons}/m^3) \times 60 \qquad \text{.......(2)}$$

2.5.3 Power to move material horizontally

If C = capacity (t/h); L=length (m); F=Power factor, then conditions are to double F if power is less than 1 kW, to multiply F by 1.5 if power lies between 1 and 2, to multiply F by 1.25 if power lies between 2 and 4and to multiply F by 1.1 if power lies between 4 and 5. Equation 3 can then be used for power calculations.

$$\text{Power (kW)} = \frac{CLF}{367} \qquad \text{.......(3)}$$

2.5.4 Lift power

If C=capacity in t/h; L=length (m); and θ=angle of inclination then the lift force can be calculated by using equation 4.

$$\text{Lift Power (kW)} = \frac{CL}{367}\sin\theta \qquad \text{....... (4)}$$

2.5.5 Total power

Total power of a screw conveyor can be calculated by using equation 5.

$$\text{Total Power (kW)} = \frac{CLF}{367} + \frac{CL}{367}\sin\theta \qquad \text{...(5)}$$

2.6 Testing Procedures for CombineHarvesters

Machinery performance, operating accuracy and grain losses varyaccording to the variety of the crop, ripening stage, condition of the crop, condition of the plant, condition of the field and travelling pattern (RNAM, 1983). Therefore, the conditions of the test have to be clearly indicated. Parameters for performance testinginclude loss in grain quantity and loss in grain quality due to seed damage. To get the total loss in the grain quantity, the grain loss caused by different parts of machines are weighed and expressed as percentages of the total grain available. Materials discharged from different parts of the combine are collected and threshed so as to get the grains that would be lost. The grains lost are collected when the machine operates at a constant speed over a measured and timed distance. Header losses are caused by the cutting mechanisms of the combine harvester. These losses are measured by placing a frame of known area in a number of locations at random over the field and picking up the shattered grains within the frame each time. A pre-harvest count is done to permit determination of the additional shatter caused by the combine.The external seed damage is obtained by checking seed samples physically; and germination tests are used to check internal damage.

2.7 Rice harvesting

Rice harvesting is the process of manually or mechanically collecting mature rice crop from the field. Harvesting consists of cutting or stripping, threshing, cleaning, hauling and bagging. In Tanzania,rice is mainly harvested, threshed and winnowed manually. In Sub Sahara Africa (SSA), farmers prefer rice harvesting at lower moisture content to ease manual rice threshing (IRRI, 2009).The recommended moisture content for easy rice threshing varies depending on the rice variety. The moisture content of about 20% dry basis is recommended for most of the rice varieties (Berhe and Somado, 2008).If rice is left longer, say one month, in the fieldshutters more, then there will be less grain and poorer rice quality due to excessive drying. Harvesting at the right time and in the right way minimizes grain losses and quality deterioration (Bell *et al*., 2003).

Good time to harvest rice in tropical area is at the moisture content of 20–25% because if rice is too dry,it will shatter and if it is too moist there will be incomplete threshing, spillage, grain damage and cracking (Bell *et al*., 2003).

Bell *et al*. (2003) addressed that, alternatively, rice should be harvested in conditions listed below:

i. When grains are firm but not brittle when squeezed between the teeth, the situations which usually take place when 80–85% of the grains are straw coloured (yellow);
ii. At 28–35 days after headingwhen the season is dry; and
iii. At 32–38 days after heading when the season is wet.

2.8 Machinery Designing

To design is to make a drawing or a plan of an object that can be made or built. Designing is a goal-directed problem-solving activity. It is a creative process in which information in the form of requirements is transformed into information in terms of technical specifications of the product or system which satisfy human need and capable of multiple production. Engineering design is the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with the maximum economy and efficiency. Steps in the design process included conceptual stage, embodiment stage and detail stage.

2.8.1 Conceptual stage

The conceptual stage involves clarification of the task in which specifications are elaborated to come up with specifications of the design concept as the output. Essential problems areidentified; function structures areestablished; solution principles are searched; concept variants are combined and firmed up; and evaluation against technical and economic criteria isdone.

2.8.2 Embodiment stage

Embodiment stage involves developing preliminary layouts and form designs whereby the best preliminary layouts areselected, refined and evaluated against technical and economic criteria to come up with the best preliminary layout. Evaluation matrix chart with the criteria including manufacturing cost, simplicity in manufacturing, availability of materials locally and suitability for purpose are used.

2.8.3 Detail stage

Detail design stage involves finalization of the detail drawings and production documents ready for manufacturing of the machine.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Description of the Study Site

Thestudy was conducted intwo sites. The first site wasthe Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) located at Themi area in Arusha Municipality where the machine was manufactured and the second site was inMawala Uchagani rice fields in Lower Moshi Kilimanjaro region where field performancetesting of the machine was done.Mawala Uchagani rice fields hasa total area of 120 acres under rice farming.

3.2 Design Parameters forPORCH Prototype

Empirically recommended design parameterswere used to design PORCH functional elements. Critical speed and capacities for different elements were used in the designing process. The important functional elements in which speeds and capacities were the major design factors are stripping drum, header auger, feeder auger, threshing drum, and blower fan. The rotational speed of the stripping drum was higher than the forward speed of the power tiller so as to avoid grain loss. To avoid grain loss in conveying system, the capacity of feeder auger was designed to match with that of header auger. The blower was designed with air volume regulator to adjust winnowing effect basing on MOG, moisture content and grain quantity. Autodesk Inventor design software was used for thedesigning and development of PORCH drawings.

3.3 Manufacturing of PORCH Prototype

PORCH prototype was manufactured by using locally available materials. The materials used were mostly metals of different forms and shapes. PORCH frame was made of mild steel (MS) angle iron with dimensions of 50 mm x 50 mm x 6 mm thick. The covers for different PORCH functional elements such as thresher, blower and screw conveyors were made of MS plate of1.5 mm thick. The drive shafts were 25 mm diameter MS. The peg type threshing drum was used. The pegs were made of 10 mm diameter round bars which were welded to 30 mm x 30 mm x 6 mm thick angle iron pieces. Some standard parts were also used for PORCH manufacturing. The standard parts used include pillow block bearings (No. P 205), bolts, nuts, washers and drive belts.

Common workshop processes and machines were used to manufacture PORCH. The main processes involved were marking, cutting, centre punching, drilling, rolling and bending of MS plates; machining of shafts; welding of different metal parts; and finishing works such as body filling and painting. Machines used were lathe, milling machines (for making keyways in shafts), hydraulic press with broaching tools (for making keyways in pulleys), press brake (for bending), guillotine shear (for cutting plates), welding machines, rolling machines and hacksaws.

The processes involved in PORCH manufacturing are easy to follow and can becarried out with simple engineering tools and machines.

3.4 PerformanceTesting ofthe PORCHPrototype

PORCH was tested by using Changchai power tiller powered by 16 hp Greaves engine. Performance testing of PORCH wasdone to obtain data on overall machine performance, operating accuracy, work capacity and adaptability to harvesting conditions. The parameters tested included harvesting time, capacity, grain loss, and materials other than grain (MOG) present in the harvested rice.Appendix 1 presents data sheet leading to availability of the mentioned parameters.PORCH testing was based on Regional Network for Agricultural Machinery (RNAM) standards of the Economic and Social Commission for Asia and the Pacificpublished in 1983. RNAM standards also conform to FAO testing and evaluation procedures for agricultural machineries published in 1994. These arethe standards adopted by CAMARTEC which has statutory rights to test agricultural machineries and equipment in Tanzania.

In performance testing, the datawere categorised as data for test conditions and data for performance measures. The data for test conditions included, condition of the crop, condition of the field, and condition of the machine and operator. Performance measureswereharvesting capacity,accuracy, work rate and labour requirements.

Proper PORCH harvesting speed wasselected based on the reduction of grain loss, efficiency of PORCH functional parts and comfort in operating the machine. Basing on these factors,Gear number 1 low was used.

The tests were carried out in the field with firm soils. Harvesting was done 10 days after the normal maturity time of rice.The rice variety wasJapan IR-64which is among the high yielding varieties preferred in Lower Moshi.

3.4.1 Condition of the crop

Condition of the crop include crop kind, crop variety, susceptibility to shattering, ripening stage, row spacing, distance between hills, plant density, condition of tillering, heath of the crop plant, inclined angle of the crop plant, moisture content of the stem and the grain at the time of harvesting as well as yields per hectare. The crop conditions have influence on the performance of harvesting machine.

3.4.2 Performance and accuracy

Data collected in performance and accuracy of the machine included cutting width, cutting height, applicable inclined angle of the crop plant, percentage of missharvesting, machine slippage, sinking of machine and grain losses.

3.4.3 Work rate and labour requirement

Data collected for work rate and labour requirement included operational Travelling speed, actual operating hours, time spent for turning and harvesting, time spent for adjustment of the machine, time spent for machine trouble, working capacity (ha/h), fuel consumption per hour (L/h) and man-hours required for both machine harvesting as well as by the use of conventional method which was harvesting by sickle.

3.5 Data analysis and comparison

Both RNAM (1983) and FAO (1994) testing standards use averages to compare different parameters. In this test, data relating to environmental conditions were taken to enable PORCH user to interpolate the performance to other local environments. During PORCH testing, the data on manhours requirement, harvesting cost per acre, grain loss, and MOG were collected for both manual and PORCHharvesting. The data obtained from PORCH harvesting were compared with the data obtained from manual rice harvesting.

3.6 Harvesting Cost

Harvesting cost for both manual and PORCHweredetermined.In machine harvesting,the costs included labour, machine depreciation, machine repair, fuel and lubricants. Labour cost includedwages for the machine operatorand the assistant operator. In calculating depreciation, life and rates for depreciation of the machineries data from FAO (2010 b) were adopted.Equation 6 below was used to calculate depreciation.

$$D\ (\text{per acre}) = P/N \quad \text{...(6)}$$

Where D=Depreciation (per acre)

P= Purchase price of the machine and

N=Number of acres to be harvested in machine life time

Repair costs are thosecosts for the repairof power tiller and PORCH.According to FAO (2010 b), accumulated repair cost for a power tiller is taken to be 100% of the machine price, and repair cost for the machines of similar nature to that of PORCH(tractor operated combine harvester) is taken to be 50% of the machine price. Fuel cost is calculated using equation 7.

$$\text{Fuel cost (TSh/acre)} = \text{Fuel consumption (L/acre)} \times \text{Fuel price (TSh/L)} \quad \text{.........(7)}$$

Lubricants cost for power tiller was taken to be 50% of the fuel cost.PORCH lubricants weretaken to be 25% of the power tiller lubricants.

In manual harvesting, the cost is only labour, which is calculated using Equation 8.

$$L = HC_{100} \times Y/(100\ \text{kg/bag})\ x(1 - MC) \quad \text{...(8)}$$

Where L=Labour cost

HC_{100}=Harvesting cost for100 kg bag

Y=Yield (kg/acre)

MC=Moisture loss due to drying to attain storage moisture (14% dry basis)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Design of PORCH for Smallholder Farmers in Tanzania

PORCH design was done so as to come up with specifications to be used for fabrication.Appendix 3presents engineering drawings for PORCH. The drawings give specifications for the use in PORCH manufacturing. The dimensions for PORCH shafts, pulleys and belts are presented in Appendix 4. The schematic table for the drive system is presented in Appendix 5.This gives a quick overview ofthe effects of power tiller speed variation to different moving functional elements of PORCH.

4.2 Description of PORCH

PORCH uses stripping drum in harvesting. The hood covering the top of the striper directs stripped rice at the header auger which conveys it to the feeder auger. The feeder auger feeds rice to the thresher in which the rice is threshed and fed into the grain tank after being cleaned by blower which separates lighter materials such as straw from the grain. The grain tank is emptied when full. The motion transmission from power tiller to PORCH is by V belts, one from the power tiller flywheel pulley to the PORCH front drive, and the other from power tiller clutch pulley to the rear drive. The front drive operates stripping drum through gears which increase the stripper’s speed. The front drive operates the header auger also. The rear drive operates the thresher, the feeder auger and the blower. Fig. 6, Fig. 7 and Fig. 8 show the main parts of PORCH.

Figure 6: PORCH hitched to a power tiller viewed from its front

1	Hood	2	Frame	3	Thresher
4	Feeder auger gearbox	5	Feeder auger	6	Stripper
7	Height wheel				

Figure 7: PORCH hitched to a power tiller viewed from the rear

8	Grain tank	9	Straw guard	10	V-belt for blower drive
11	Blower	12	Grain duct		

Figure 8: PORCH hitched to a power tiller viewed from one side

13	Height wheel sleeve	14	V-belt for feeder auger gearbox drive	15	Grain tank supporting rod
16	V-belt for thresher drive	17	V-belt for header auger drive	18	V-belt for stripping drum drive

4.3 Field Performance Test Results

4.3.1 Operation, adjustment and precision of PORCH

PORCH operation was easy and manageablebecause it was easy to train operatorsto operate it.The parts of the machine to be adjusted were stripping height which wasadjusted by usingclamping bracket and adjusting handle.Other adjustments were drive belt tensioning which transmits motion from the power-tiller to PORCH. Belt tensioners were used as the clutch to disconnect and connect motion from the power tiller to PORCH. PORCH hastwo tensioners one at the front drive (flywheel pulley) and the other at the rear drive (clutch pulley) of the machine. When the tensioners were loosenedthe belts slipped hence no motion was transferred from the power tiller to PORCH.However the adjustments were cumbersome because two operators were needed to actuate the PORCH parts by tensioning thetwo tensionersat once so as to reduce slipping time which could result intowear and tearof the belt.

Many parts of PORCH were operated by belt drive which needed some adjustments, which if not be done properlycould result into unnecessary slips.

PORCH was constructed to eject straw at the rear of the machine where the PORCH operator is stationedduring operating the machine. Hence, it was necessary for the PORCH operator to wear protective gears(goggles, nose musk, dust coat and cap) for protection against straw and dust.

PORCH was attached to the power tiller without rubber mountings which resulted into a lot of noise caused byvibration which was transmitted from power tiller to PORCH.It was also noted that the PORCH thresher delayed the ejection of straws. This problem was solved by stopping PORCH from moving for a while with its thresher operating.

The weight of PORCH was found to be 353 kg.Reduction of its weight would improve its performance. PORCH grain tank outlet had large clearance which could not be tightly closed by its cover. That necessitated covering it by pieces of clothes and sacks inorder toreduce grain leakage.

4.3.2 PORCH specifications

The combine harvester was named asKilimo Kwanza PORCH so as to address the importance of such machines in KKIGR. The model of the machine is PORCH 1160. The number1160 in the model is the theoretical width (the width of the stripper) in millimetres that the machine can harvest in a run.PORCH specifications are given in Table 1.

Table 1: PORCHspecifications

Parameter	**Description**
Make	Kilimo kwanza PORCH
Model	PORCH 1160
Power tiller used for PORCH testing	Greaves 16 hp engine mounted to Changchai power-tiller
Machine (PORCH) size (L * W * H)	2460 mm * 1575 mm *2105mm
Total weight of the bare machine	353 kg
Mechanism of harvesting	Stripper header
Type of side delivery and discharge device	Delivery is by auger and discharge is by gravity
Type of elevating device	Screw conveyor (Auger)
Workers required for continuous operation	2
Minimum stripping height	260 mm
Maximum stripping height	680 mm
Machine adjustments needed	Strippingheight and drive belt tensioners
Power transmission system	V-belts, chain and gears
Work capacity of machine	0.17 ha/h (0.42 acre/h)
Stripping width	1160 mm

4.3.3 Preliminary results

Preliminary information and description of test condition is presented in Table 2, Table 3presents numeric values of test conditions of crop at harvestingand Table 4 presents numeric values of performance measureswhich include thecondition of the field, fuel consumption, and grain loss.

There was much shattering (20 g/m^2≈ 81 kg/acre) in the field due to low grain moisture content (19.2% db) as compared to recommended moisture content (20% db) for rice harvesting in tropical areas. However, this low moisture content of the grain has advantage in rice threshability, as rice becomes looser. Line spacing (17.2 cm) and hill distance (14.6 cm) was good enough as no space was lost in the field. However, the field was slightly overpopulated as the recommended spacing for that rice variety in Lower Moshi is 20 cm (line spacing) by 15 cm. (hill distance). This resulted in plant populationof about (41.2 plants/m^2).The crop had both optimal plant height (93.4 cm), number of tillersper plant (14.1 g) and weight of grains per head (2.6 g) which is due to good agronomic practices which result in good crop yield (10241 kg/ha ≈4145 kg/acre) at harvesting moisture content (19.2% db). Small inclined angle (25.3^o) of plant has resulted in smalldiameter (3.1 mm) of stem at stripping height of the plant because there was no need of harvesting at lower heights (having lager stem diameters) as most of the plants were almost upright. The presence of high values of soil moisture (32.7% db,) resulted in high plantmoisture content of straw (72.3% db).

The field was compacted enough (cone index =473) so as no excessive wheel slip was noticed during the test.PORCH took 16 min to harvest a plot of 23.3 m by 11m (256.3 m^2 ≈ 0.421acre/h). By such a motion PORCH could take two hours and 23 min to complete harvesting one acre of rice. Short time (18 min) needed for PORCH adjustments promises possibility of maximizing time use efficiency in PORCH harvesting as most of the time can be used for harvesting rather than adjusting the machine. PORCH affordablefuel consumption (0.27 L≈4.26 L/acre) hence good fuel use economy.

The average values of grain loss in PORCH harvesting include header loss (13.3%),conveying loss (13.2%), and shoe loss (2.4%). The three losses make a total loss of 28.9%. This is too much loss as compared to manual harvesting where the loss was 14.8%. Both amounts of losses (in PORCH harvesting and manual harvesting) are higher as compared to acceptablecombine harvester losses (about 5.4 %) as indicated by some empirical studies (Malik *et al*., 1990).

Table 2: Preliminary information and description of test conditions

Parameter	**Description/ value**
Date of test	20-26 June, 2012
Average effective working width	1020 mm
Harvesting pattern	Circuited pattern round corners
Crop variety	Japan IR 64
Date of sowing/planting	15/02/2012
Normal period of maturity days after sowing	90 days
Harvesting time after normal maturity period	10 days
Location	MawalaUchagani in Lower Moshi
Topography	Horizontally level field
Type and characteristics of soil	Clay loam soil with some cracks
Soil surface	Smooth surface

Qualitative assessment (excellent, good, fair, bad, rough, etc.)	Good

Table 3: Numeric values of test conditions of crop at harvesting

Test parameter	Block													
Condition of crop at harvesting	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Average**	**CV**
Shattering at maturity(g/m^2)	28.5	17.6	12.9	22.8	22.1	18	17.3	21.3	16	25.6	18.2	20	**20.0**	**21.5**
Row spacing (cm)	15	22	14.6	17.2	19	16.3	16	17	18.8	15	17	18.7	**17.2**	**12.4**
Hill distance (cm)	11	13	15	10.5	15	14.3	15.6	13.9	18	16	17	16.2	**14.6**	**15.4**
Plant height (cm)	89	57.5	91.9	95.8	92	86.4	90	124	92.5	110	94.6	97	**93.4**	**16.5**
Inclined angle of plant (degree)	42	28	22	18	23	32	28	19	26	17	25	24	**25.3**	**27.1**
Plant population per square metre	38	44	40	45	41	47	42	39	41	40	35	42	**41.2**	**7.8**
Number of tillers/heads per plant	9	18	17	13	14	12	18	13	17	11	8	19	**14.1**	**26.3**
Weight of grains per head (g)	3.1	2.4	1.7	2.2	1.9	3.3	2	3.2	2	2.9	4.1	2.4	**2.6**	**27.7**
Diameter of stem (at stripping height in mm)	1.9	2.7	2.5	3.4	3.2	4.1	4	4	3.5	2.2	3.3	2.8	**3.1**	**23.1**
Moisture content of straw (% db)	74	71.3	71.3	72.6	73	72.9	69	73.5	73	70	72.9	74	**72.3**	**2.2**
Moisture content of grain (% db)	19.3	18	18.5	16.4	18.4	15	22	18.2	20	22.6	21	21	**19.2**	**11.7**
Yield of grain at field moisture content (kg/ha)	11200	9450	9840	9610	10700	10203	10236	11200	9900	10184	10134	10231	**10241**	**5.403**

Table 4: Numeric values of performance measures

Parameter	Block													
Condition of the field and fuel consumption	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Average**	**CV**
Soil moisture (% db)	25.3	36.3	34.1	26.5	33	39	32.8	37.4	32.7	29.6	32.7	33	**32.7**	**12.4**
Cone index (kPa)	455	495	485	499	422	460	473	469	462	500	465	491	**473**	**4.8**
Time taken (minutes)	15	14	13	16	22	19	15	16	17	18	14	13	**16**	**16.6**
Length of test plot (m)	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	**23.3**	**0**
Width of test plot (m)	11	11	11	11	11	11	11	11	11	11	11	11	**11**	**0**
Time lost owing to adjustments	20	16	17	14	16	25	21	17	16	17	19	18	**18**	**16.2**
Fuel consumption (L)	0.22	0.35	0.3	0.31	0.21	0.31	0.24	0.26	0.35	0.2	0.31	0.2	**0.27**	**20.9**
Parameter	**Block**													
Grain loss in PORCH harvesting (%)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Average**	**CV**
Header loss (%)	11.7	12.4	12	13	11	14.1	12.2	6.6	10	32	11.8	12.6	**13.3**	**46.5**
Conveying loss (%)	20.4	12.1	10.4	15	11.2	13.2	13	16.1	12.2	9.3	15.4	9.9	**13.2**	**23.8**
Shoe loss (%)	2.5	1.8	2.4	4	2.3	2.4	2.6	1.7	2.2	2.6	2.5	2.3	**2.4**	**23.3**
Total loss (%)	34.6	26.3	24.8	32	24.5	29.7	27.8	24.4	24.4	43.9	29.7	24.8	**28.9**	**8.3**
Loss in manual harvesting (%)	15.4	15.3	17	13.3	14.7	14.2	13.9	15.2	16.4	14.9	12	15.8	**14.8**	**9.2**

4.3.4 Performance Measures

Table 5 and Table 6presentTime, capacity, cost, grain loss and MOG for manual harvesting and PORCH harvesting respectively. The two tables make Completely Randomised Block Design(CRBD). CRBD is research design in which experimental units to which the treatments are applied are subdivided into homogeneous groups called blocksso that the number of experimental units in a block is equal to the number of treatments to be tested.

The tables (Table 5 and Table 6)gives comparison of test parameters for both PORCH and manual harvesting. Manual harvesting uses much time(255.92man-h/acre) as compared to time (4.779 man-h/acre)used for PORCH harvesting. The corresponding; harvesting capacity was 0.0039acre/h for manual harvesting and 0.421acre/h for PORCH harvesting. It was found that manual harvesting was more expensive (TSh.181250/acre) as compared to PORCH harvesting cost (TSh.30151/acre).

Manual harvesting grain loss (14.8%) was lower as compared to PORCH harvesting loss (28.8%). MOG (8.3%) in PORCH harvesting was lower than amount of MOG (3.2%)in manually harvested rice.

In testing significance of PORCH harvesting vis-a-vis manual harvesting F test was used at 1% significance level at 2 and 11 degrees of freedoms for the treatments and error terms respectively. The results are presented in Appendix 2.

Table 5: Time,capacity, cost, grain loss and MOG for manual harvesting

Parameter	Block												Average	CV
	1	2	3	4	5	6	7	8	9	10	11	12		
Harvesting time (man-h/ acre)	264	258	256	285	252	263	268	262	226	224	274	239	**255.92**	**7.158**
Capacity (acre/h)	0.0038	0.0039	0.0039	0.0035	0.0040	0.0038	0.0037	0.0038	0.0044	0.0045	0.0036	0.0042	**0.0039**	**7.158**
Harvesting cost (TSh/ acre)	150000	195000	240000	195000	195000	195000	165000	165000	195000	150000	150000	180000	**181250**	**14.74**
Grain loss (% of harvested grain)	16.1	15.2	12.7	12	15	15.4	14.6	12.4	18.8	14	15.3	16.6	**14.842**	**12.91**
MOG (%)	8.7	8.5	7.2	9	7.9	9.2	8	7.4	8.1	7.5	8.2	9.9	**8.3**	**9.625**

Table 6: Time, capacity, cost, grain loss and MOG for PORCH harvesting

Parameter	**Block**												**Average**	**CV**
	1	2	3	4	5	6	7	8	9	10	11	12		
Harvesting time (man-h/ acre)	5.527	4.474	4.263	4.790	4.711	4.421	4.816	5.158	4.211	5.053	5.079	4.842	**4.779**	**8.197**
Capacity (acre/h)	0.362	0.447	0.469	0.418	0.425	0.452	0.415	0.388	0.475	0.396	0.394	0.413	**0.421**	**8.197**
Harvesting cost (TSh/acre)	27235	34574	31750	32315	26667	32315	28365	29491	34574	26105	32315	26105	**30151**	**10.62**
Grain loss (% of harvested grain)	28.5	27.9	29.5	28.4	27.6	29	28	28.4	28.9	29.3	31	29.8	**28.858**	**3.286**
MOG (%)	4.1	2.7	3.4	3.2	4.6	2.8	2.9	2.9	2.6	3.1	3	3	**3.1917**	**18.53**

In the study it was found that PORCH harvesting is betterthan manual harvesting in terms of harvesting time, capacity, MOG reduction and cost reduction. However, manual harvesting was better than PORCH harvesting in grain loss reduction.

There is a bigheader loss owing to flatness of the angle irons holding the stripper bearings in the front of the PORCH.Large conveying loss is due to inefficient pneumatic conveying system thatlinksthe header auger to the feeder auger.Higher grain losses in PORCH harvesting are due to large values of header losses and conveying losses which can be improvedby sealing of leakages in somePORCH functional elements (feeder auger, thresher, blower and grain tank) and attaching dividers (devices with sharp edges to direct crop to the desired direction) in front of PORCH.

The use of hand tools makes manual harvesting expensive.This is because it takes a number of days for a group of people to complete harvesting an acre.Eight people used four days to harvest, thresh and clean a grain from one acre field. While a PORCH operated by two people takes an average of two hours and 23 minutes to harvest one acre of rice.

More MOG in manually harvested rice was due todependence on natural wind for winnowing. Thus, type of harvesting depended much on the presence of enough wind speeds.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

PORCH for smallholder rice farmers in Tanzania was designed, constructed and tested. Comparisons between PORCH harvesting and manual harvesting in terms of man-hours per acre, harvesting capacity (acre/h), harvesting cost (TSh/acre), grain loss(%) and MOG (%) were carried out. In PORCH harvesting, man-hours per acre, harvesting capacity, harvesting cost, grain loss and MOG were 4.79 h/acre, 0.421 acre/h, and TSh. 30151/acre, 28.86% and 3.19% respectively. In manual harvestingman-hours, harvesting capacity, harvesting cost, grain loss and MOG were 255.9h/acre, 0.0039 acre/h, TSh. 181250/acre,14.84% and 8.3% respectively. Average fuel consumption was 0.27 L per plot (4.26 L/acre). Thus, the test results show thatPORCH is more efficient inthe reduction of labour (man-h); harvesting capacity, harvesting cost and MOG;while manual harvesting was better only in the reduction of grain loss.

The use of PORCH will enable rice growing communityto increasethe use of power tillers;increase the quality of rice produced due to timely harvesting and threshing; substitute labour from rice harvesting to other economic activities; and increase interest in rice production because of the reduction oftoilage and drudgery. These salient features of PORCH willattract more peopleinto rice production business.In general, PORCHadds tonic to KKIGR by providingappropriate technology to Tanzanian environment.

5.2 Recommendations

Based on the advantages of mechanization provided by PORCH,there is the need to improve PORCH and explore its full potential. Thus,the following are recommended for the future improvement of the PORCH:

i. Lighter materials should be used in PORCH construction so as to reduce machine weight.
ii. Grain loss in PORCH should be minimized by improving some of its functional elements (grain tank, feeder auger, blower and thresher), and provision of dividers to the front of PORCH.
iii. PORCH should be provided with only one motion transmission pulley from the power tiller so as to enable one person to actuate rotations of PORCH parts immediately after starting.
iv. Belt drives for the stripper and header auger should be replaced with a chain drive to avoid the problem of slippage and hence wearing of belts. However, this chain drive should be well protected so as to avoid excessive noise as chains can cause noise.
v. The position of straw outlet should be changed from the rear to the front of the thresher so as to avoid throwing the straw to the operator.
vi. There should be a mechanical way of conveying harvested rice fromthe header auger to the feeder auger so as to replace the pneumatic system that is currently in use because it has been proven not to be effective for the machine.
vii. The machine should be used with other clutching mechanism rather than using belt tensioning as clutching mechanism can avoidexcessive tear and wear of the belts.
viii. The PORCH shouldbe fitted with mountings to the power tiller frame so as to avoid excessive vibration, which makes the machine fail to operate in higher speeds.

ix. The thresher of the machine should be redesigned and reconstructed to allow smooth and faster flow of the straw so as to avoid delays in the straw outflow.

x. SMMFs andIndustrial Support Organizations (ISOs) such as Tanzania Engineering and Manufacturing Development Organization (TEMDO), CAMARTEC, Tanzania Industrial Research Development Organization (TIRDO) and Small Industries Development Organization (SIDO) should be involved in PORCH mass-producing so as to make it readily available to the farmers.

xi. Further studies should be conducted to determine the performance measure of the PORCH in different cereal crops such as wheat and barley harvesting as well as determining PORCH performance at different speeds.

xii. Testing of PORCH harvested grains quality should be done so as to be assured in quality of grains to be used as seeds.

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APPENDICES

Appendix 1: Data Sheet for PORCH performance testing

Particular	**Value/description**
I. TEST CONDITIONS	
a) Conditions of crop with reference to field to be harvested	
Crop variety	
Susceptibility to shattering at maturity: Yes/No	
Date of sowing/planting	
Row spacing (cm)	
Hill distance (cm)	
Seed rate (kg/ha)	
Normal period of maturity days after sowing	
Harvesting days before normal maturity period	
Harvesting days after normal maturity period	
Plant height (cm)	
Inclined angle of plant	
Plant population per square metre	
Number of tillers/heads per plant	
Weight of grains per head	
Diameter of stem at stripping height in mm	
Moisture content of straw	
Moisture content of grain	
Yield of grain (kg per ha) at field moisture content	
Yield of grain (kg per ha) at 14% moisture content	
b) Condition of the field to be harvested	
Location	
Length (m)	
Width (m)	

Area (m^2)	
Topography	
Type and characteristics of soil	
Soil surface	
Soil moisture (% db)	
Cone index	
Qualitative assessment (excellent, good, fair, bad, rough, etc.)	
Any other	
c) Condition of operator	
Skill of operator	
Wage of operator	
Wage of labour engaged in manual harvesting	
II. FIELD PERFORMANCE	
Date of test	
Starting time	
Finishing time	
Actual operation	
Time lost owing to turning and number of turns	
Time lost owing to refuelling	
Time lost owing to clearing, clogging, etc.	
Time lost owing to adjustments	
Time lost owing to repair	
Actual area covered	
Effective working width	
Effective field capacity (ha/h)	
Field efficiency (%)	
Speed of machine (m/min) and gear used	
Fuel consumption (L)	
Fuel consumed per working hours (L/h)	

Fuel consumption (L/ha)	
Height of cut (stubble height) (cm)	
Harvesting pattern	
MATERIALS OTHER THAN GRAIN (MOG) IN HARVESTED RICE	
a) Materials other than grain in machine harvested rice	
Weight of MOG in a weighed rice sample (g)	
Weight of rice sample (g)	
MOG present (%)	
b) Materials other than grain in manually harvested rice	
Weight of MOG in a weighed rice sample (g)	
Weight of rice sample (g)	
MOG present (%)	
GRAIN LOSSES	
a) Pre-harvest loss on the ground in gm (Wg_0) per m^2 (Wg_0)	
b) Grain losses in machine harvesting	
Header losses (owing to stripper during crop stripping)	
Weight of loose grain on ground in gm/m^2 (Wg_1)	
Weight of grains from cut ears fallen on ground in gm/m^2 (Wg_2)	
Weight of the grains from uncut ears after the harvesting in gm/m^2	
Total average: $Wg_t = Wg_1 + Wg_2 + Wg_3$	
Percentage of header loss (Yg: Yield in gram/m^2) $H = \frac{Wg_t - Wg_0}{Yg} \times 100\%$	
Conveying loss (loss owing to gathering and discharging devices)	
Weight of loose grain and grain from cut ears fallen outside of cutting width in gm/m^2 of harvested area (C_g)	
Percentage of conveying loss (C) $C = \frac{C_g}{Y_g} \times 100\%$	

i. Cylinder loss: *The percentage loss of unthreshed seed from the cylinder of the machine.*	
Percentage of cylinder loss (L) $L = \frac{Wg_c}{Y_g}$	
ii. Shoe losses: *include free seed carried over the shoe (cleaning unit) in a blanket of chaff or blown over by an excessive air blast.*	
Shoe loss (S) $S = \frac{Wg_s}{Y_g}$	
Other miscellaneous losses percentage (M)	
Total machine loss percentage (T) is given as: $T = H + C + L + S + M$	
a) Grain loss due to manual harvesting	
LABOUR REQUIREMENTS	
a) Labour requirement for machine harvesting	
Actual number of persons required before test for preparing field for harvesting, i.e. cutting headland with sickle.	
Number of labourers employed to prepare the field by hand before machine harvesting	
Duration of engagement	
Total man hours used	
Number of persons required after machine operation	
Number of persons employed for hand operations after machine harvesting	
Duration of engagement	
Total man hours used	
Labour requirement to operate the machine	
Number of operators required	
Duration of engagement (h)	
Total man hours used	

b) Labour requirement for manual harvesting	
Number of persons in a crew required to harvest one acre by hand	
Duration of engagement	
Total man hours used	
HARVESTING COST	
Cost of harvesting a metric tonne (1000 kg) by machine	
Cost of harvesting a metric tonne (1000 kg) by hand	
OTHER MACHINE OPERATION FACTORS	
Ease of operation of machine (easy, manageable, difficult)	
Ease of adjustment and precision of machine (good, acceptable, poor)	
Additional adjustment and precision of machine	
Additional information and remarks if any	

Appendix 2: F values for man-hours, harvesting capacity and harvesting cost at 1% significance Level

Comparison of man hours

SoV	Df	SS	MS	F calculated	F tabulated
Blocks	11	1929.0013	175.36375	1.0798958	4.47
Treatments	1	339174.15	339174.15	2088.6457	9.65
Error	11	1786.2846	162.38951		

Comparison of capacity (acre/h)

SoV	Df	SS	MS	F calculated	F tabulated
Blocks	11	0.0064804	0.0005891	1.0084436	4.47
Treatments	1	1.0445352	1.0445352	1787.9821	9.65
Error	11	0.0064262	0.0005842		

Comparison of harvesting cost per acre

SoV	Df	SS	MS	F calculated	F tabulated
Blocks	11	3.928E+09	357102273	1	4.47
Treatments	1	1.457E+11	1.457E+11	408.02676	9.65
Error	11	3.928E+09	357102273		

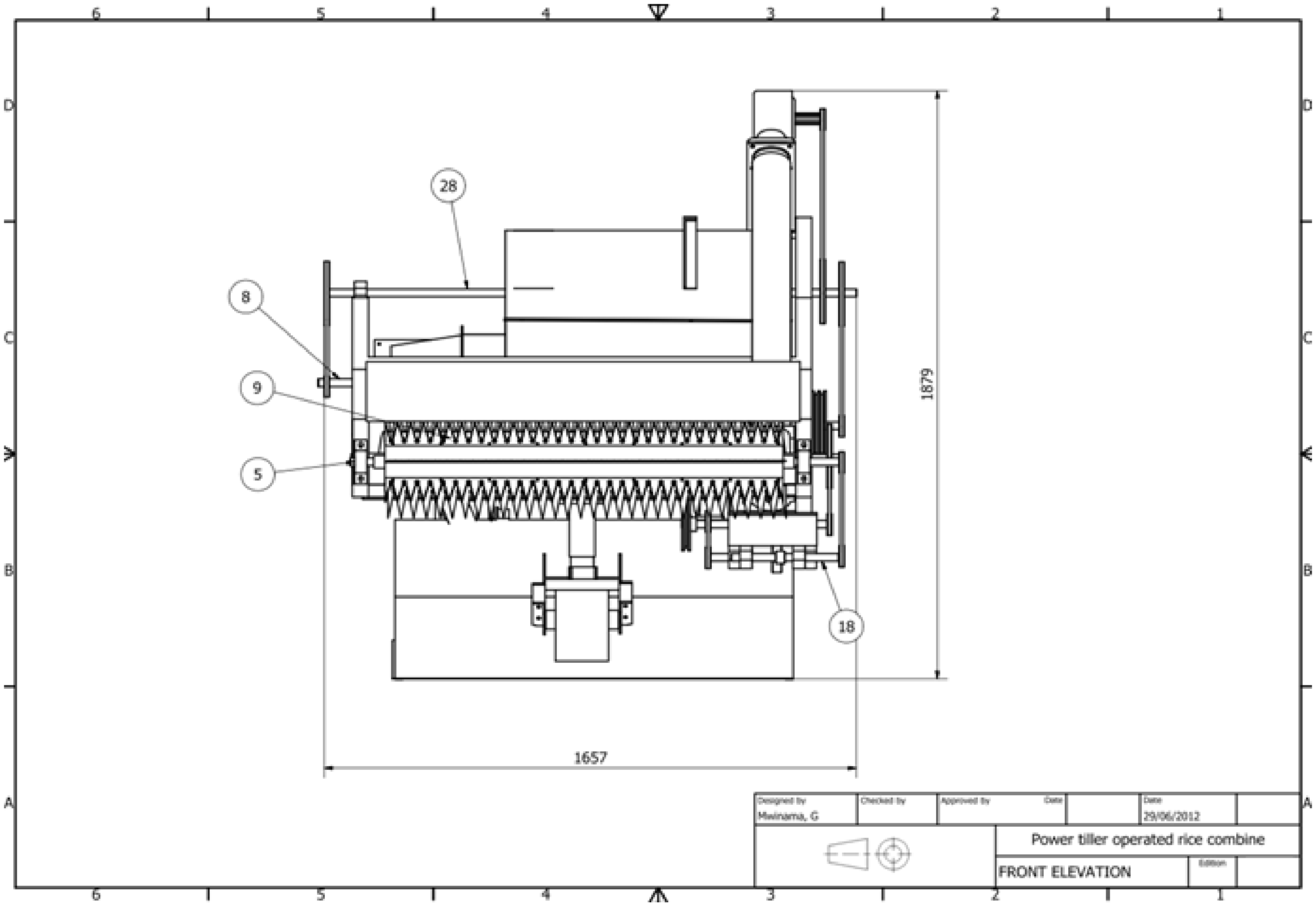
Comparison of grain loss (%)

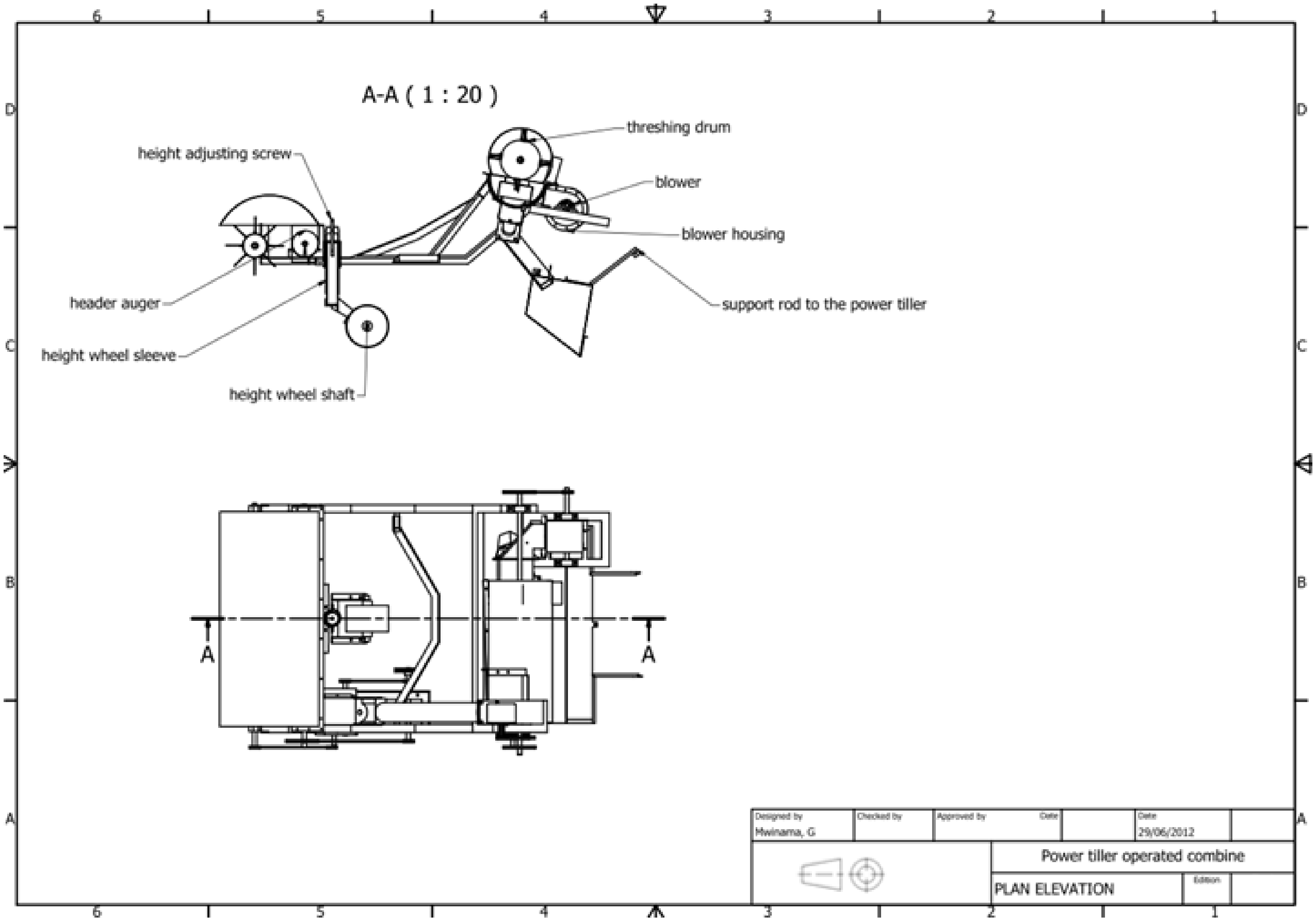
SoV	Df	SS	MS	F calculated	F tabulated
Blocks	11	27.92	2.5381818	1.2476354	4.47
Treatments	1	1178.8017	1178.8017	579.43629	9.65
Error	11	22.378333	2.0343939		

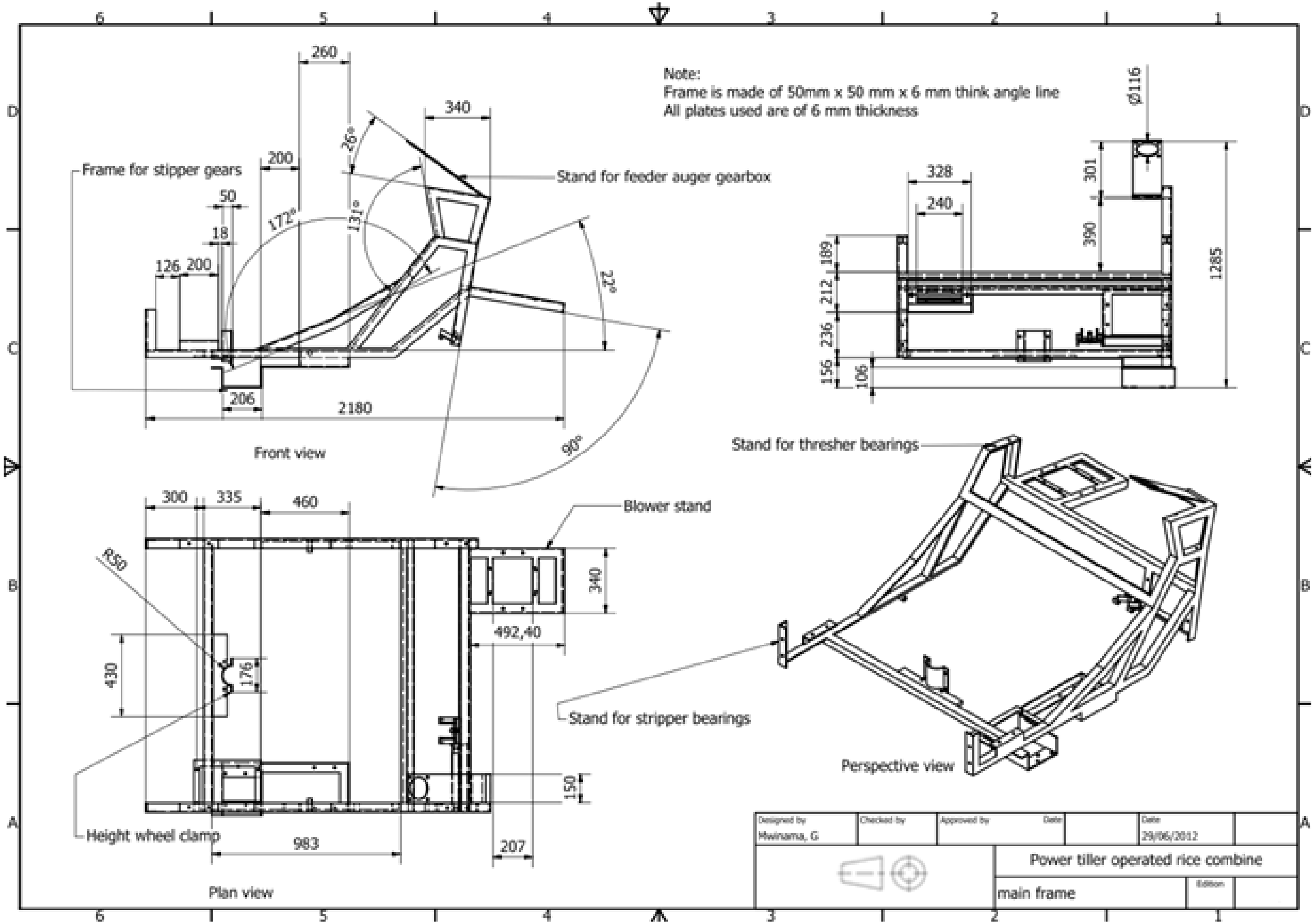
Comparison of MOG (%)

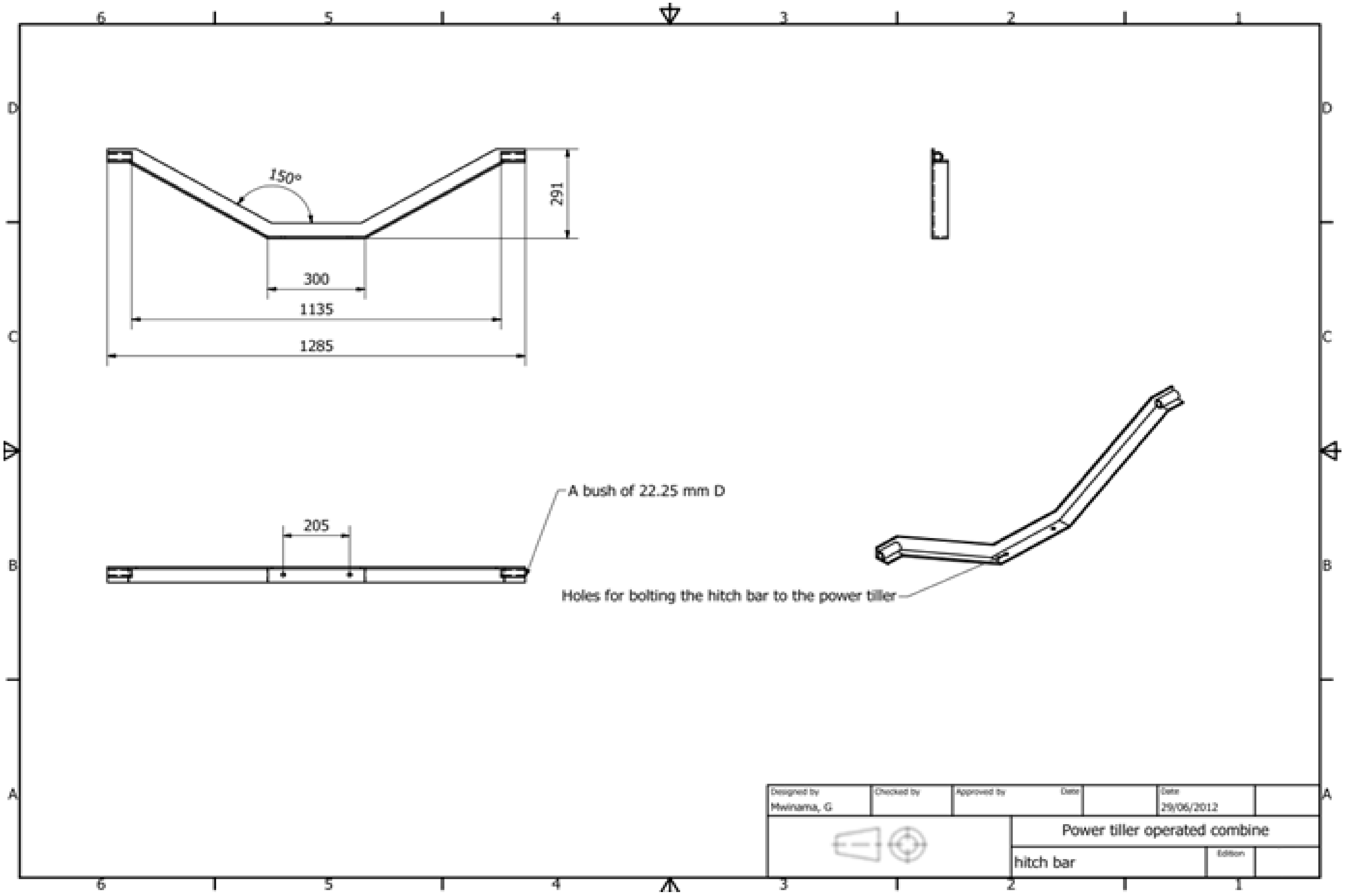
SoV	Df	SS	MS	F calculated	F tabulated
Blocks	11	4.8145833	0.4376894	0.7951965	4.47
Treatments	1	156.57042	156.57042	284.45799	9.65
Error	11	6.0545833	0.5504167		

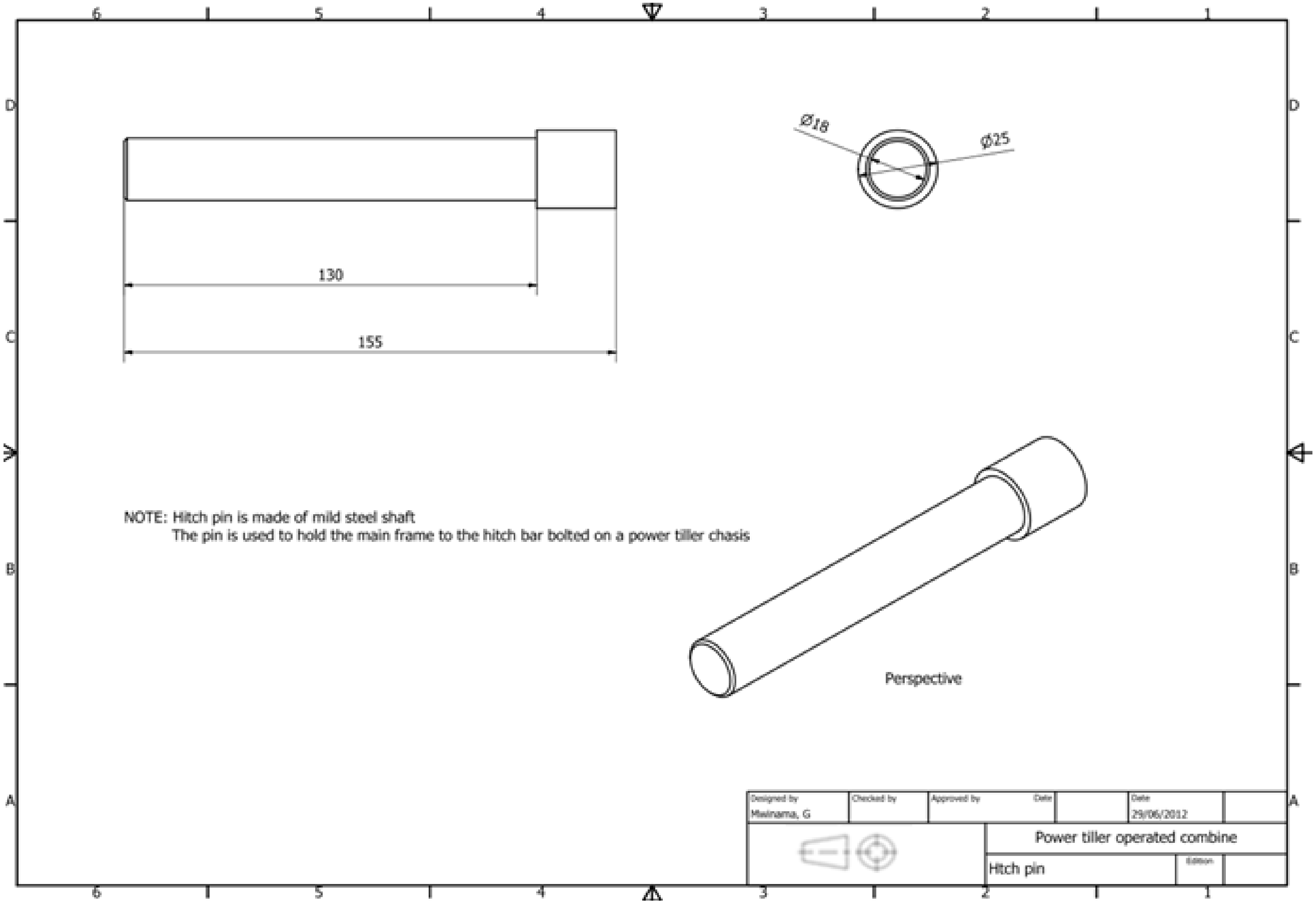
Appendix 3: Engineering drawings for PORCH

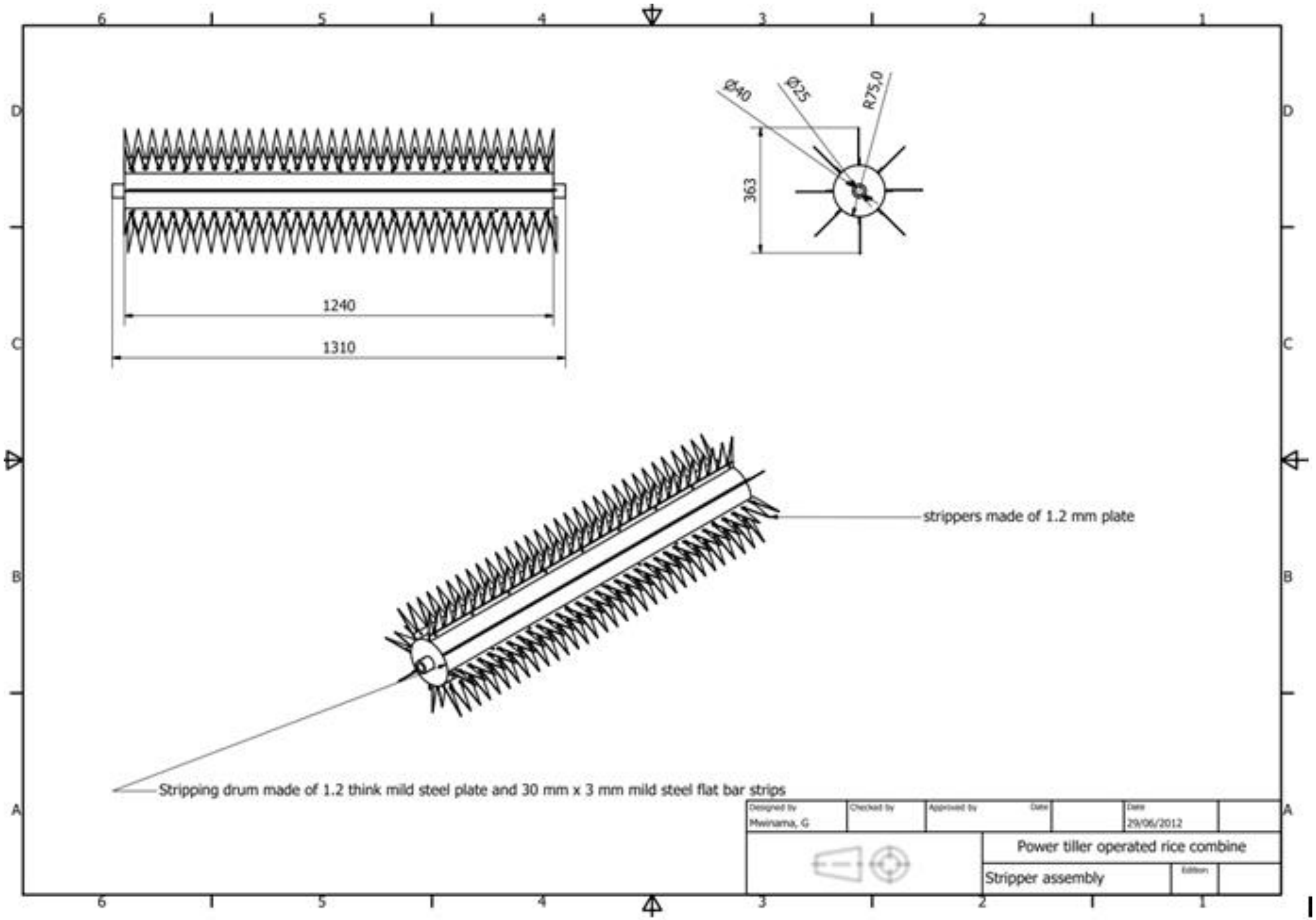



A-A (1 : 20)
threshing drum
height adjusting screw
blower
blower housing
support rod to the power tiller
header auger
height wheel sleeve
height wheel shaft
A
A
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
29/06/2012
Power tiller operated combine
PLAN ELEVATION
Edition

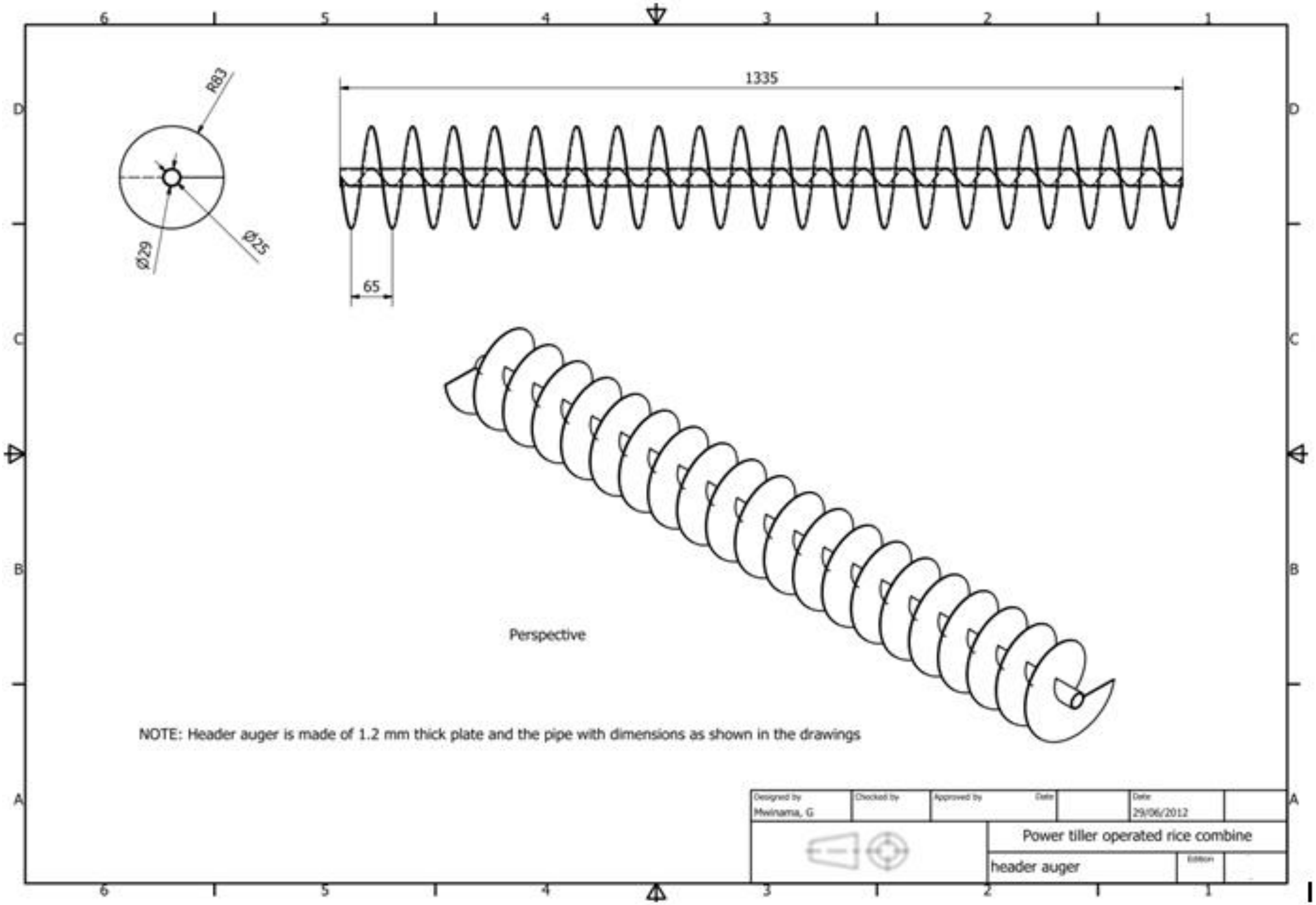

Note:
Frame is made of 50mm x 50 mm x 6 mm think angle line
All plates used are of 6 mm thickness
Frame for stipper gears
Stand for feeder auger gearbox
Front view
Stand for thresher bearings
Blower stand
Stand for stripper bearings
Perspective view
Height wheel clamp
Plan view
Designed by
Mwinama, G
Checked by
Approved by
Date
29/06/2012
Power tiller operated rice combine
main frame
Edition

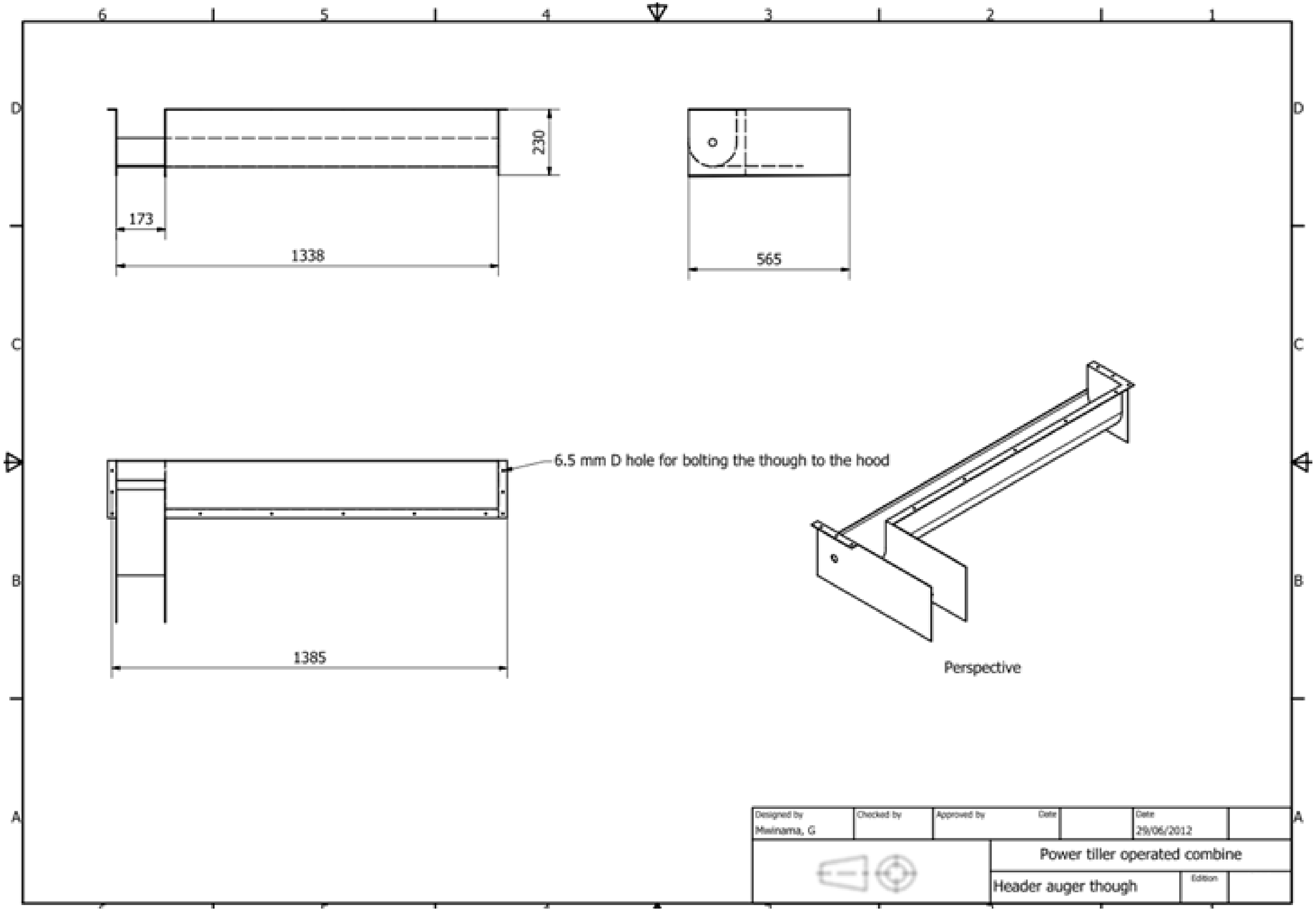

150°
291
300
1135
1285
205
A bush of 22.25 mm D
Holes for bolting the hitch bar to the power tiller
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
29/06/2012
Power tiller operated combine
hitch bar
Edition


Ø18
Ø25
130
155
NOTE: Hitch pin is made of mild steel shaft
The pin is used to hold the main frame to the hitch bar bolted on a power tiller chasis
Perspective
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
29/06/2012
Power tiller operated combine
Htch pin
Edition

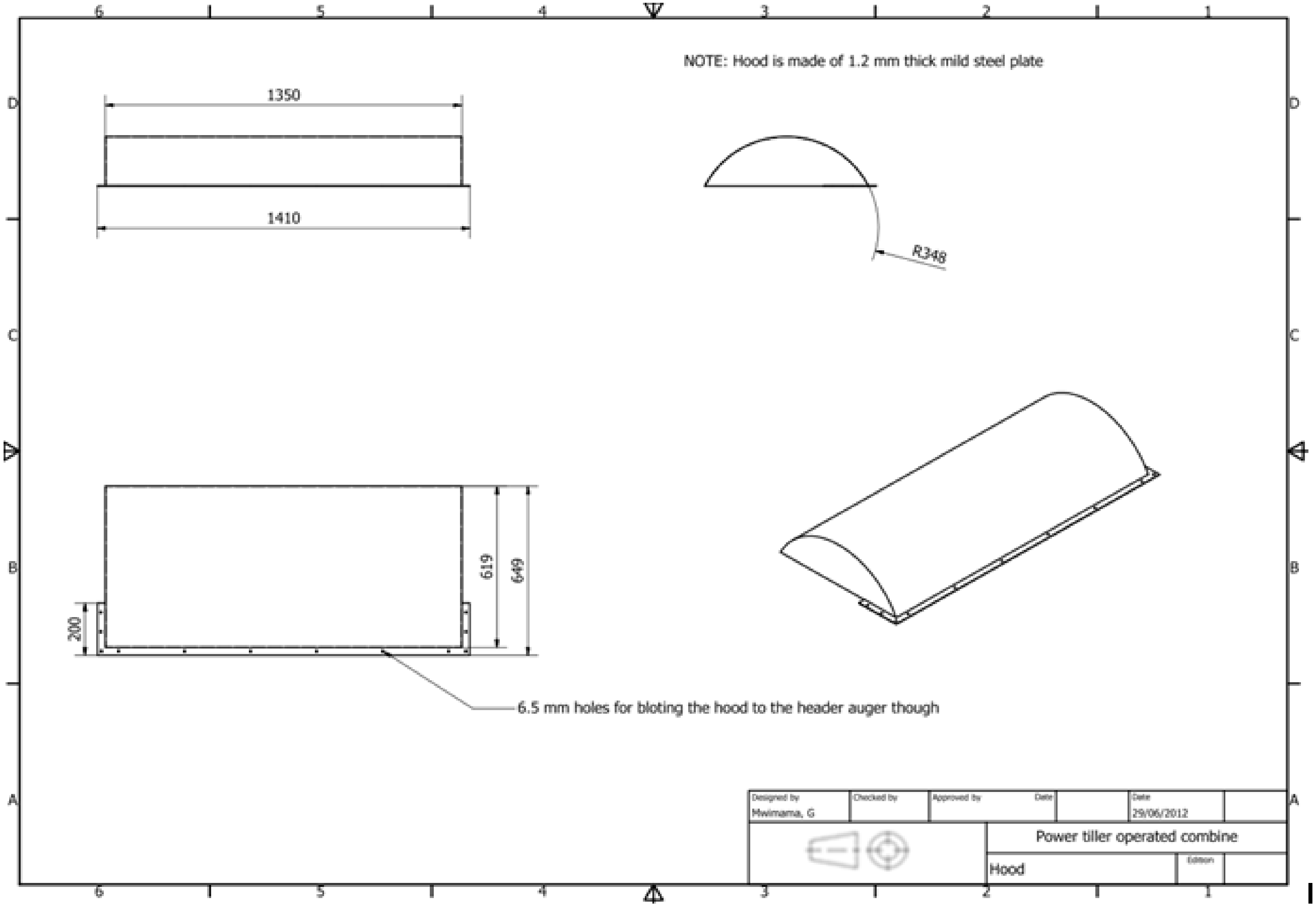


1240
1310
Ø40
Ø25
R75,0
363
strippers made of 1.2 mm plate
Stripping drum made of 1.2 think mild steel plate and 30 mm x 3 mm mild steel flat bar strips
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
29/06/2012
Power tiller operated rice combine
Stripper assembly
Edition

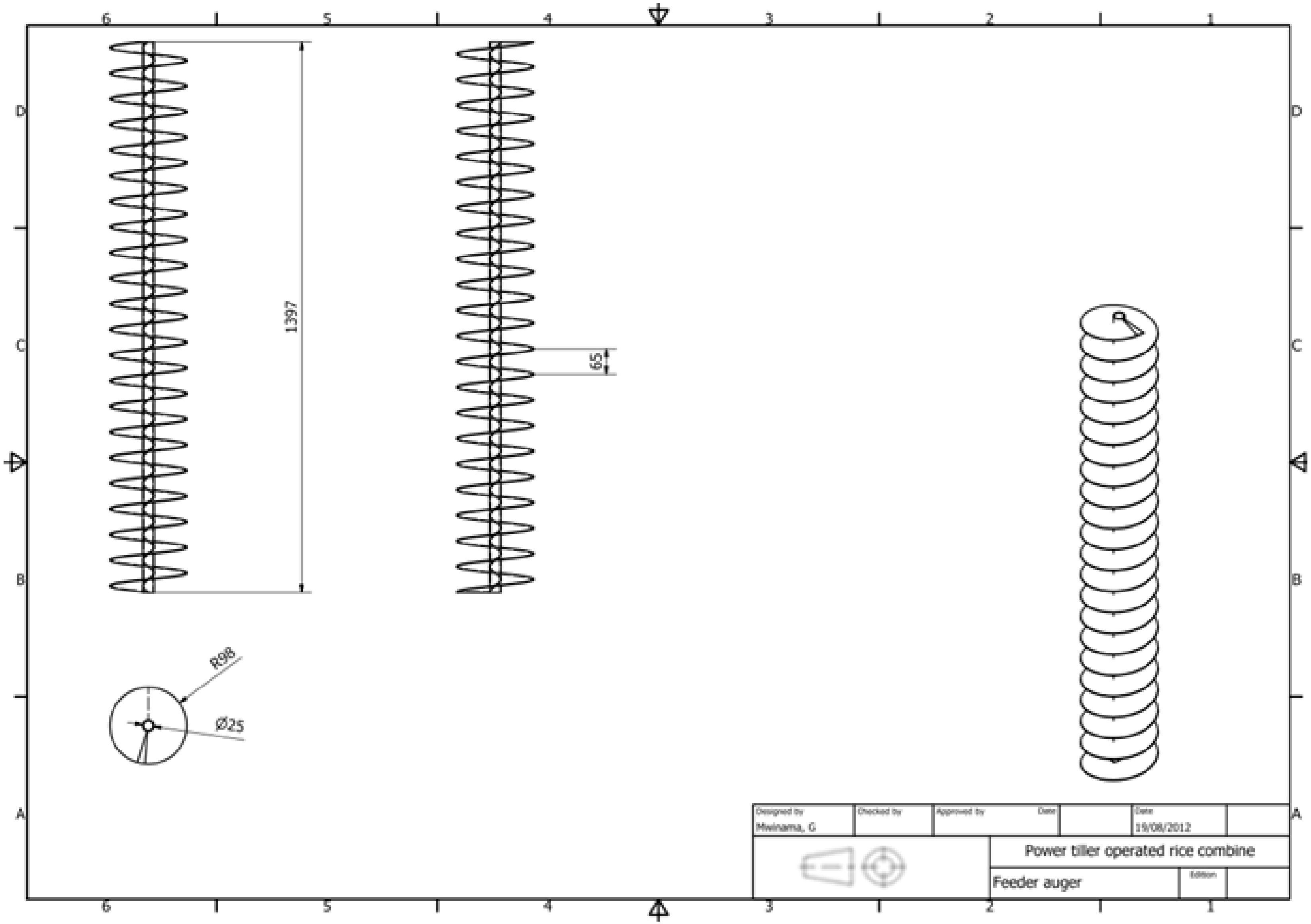

R83
1335
Ø29
Ø25
65
Perspective
NOTE: Header auger is made of 1.2 mm thick plate and the pipe with dimensions as shown in the drawings
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
29/06/2012
Power tiller operated rice combine
header auger
Edition



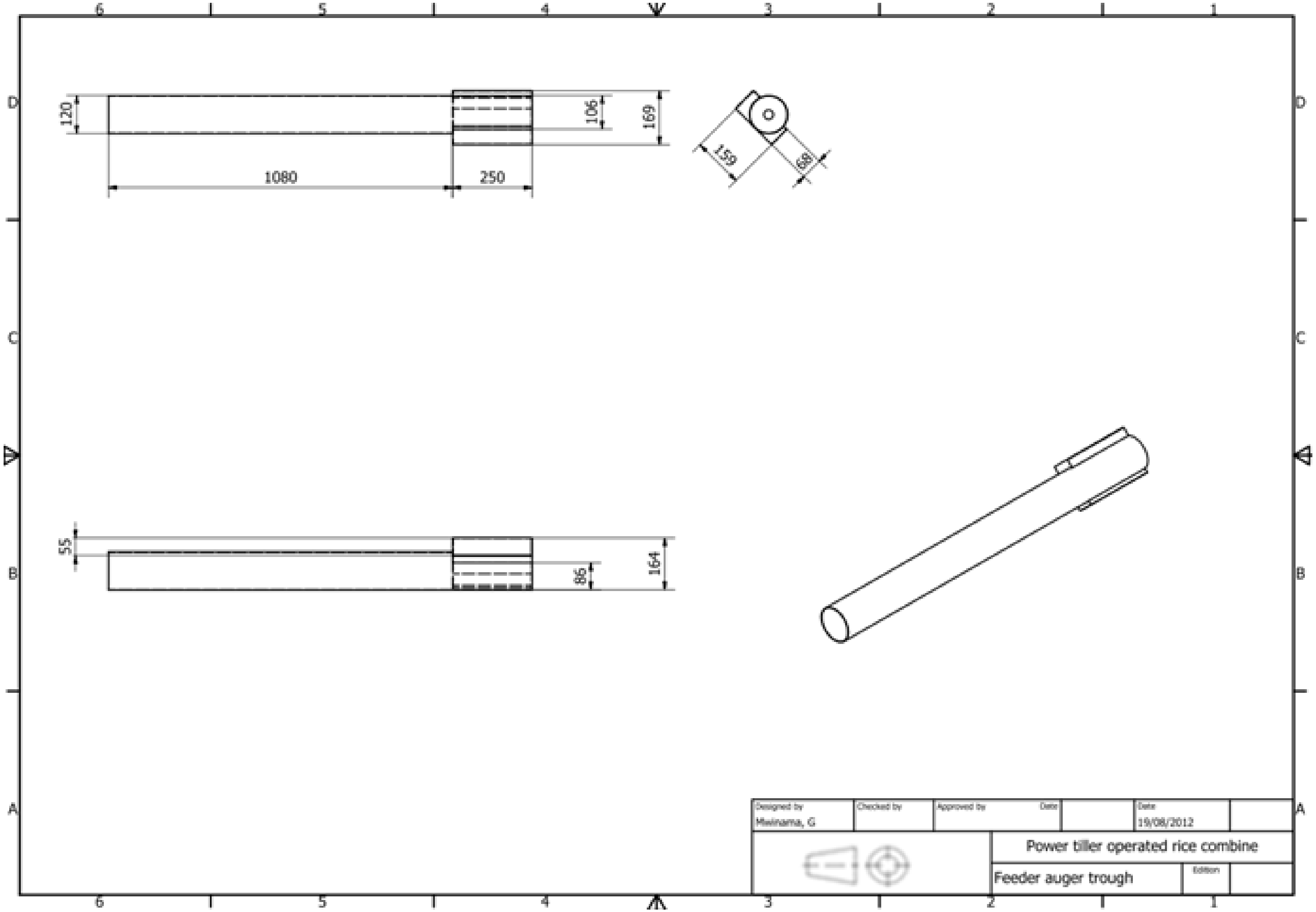
173
1338
230
565
6.5 mm D hole for bolting the though to the hood
1385
Perspective
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
29/06/2012
Power tiller operated combine
Header auger though
Edition

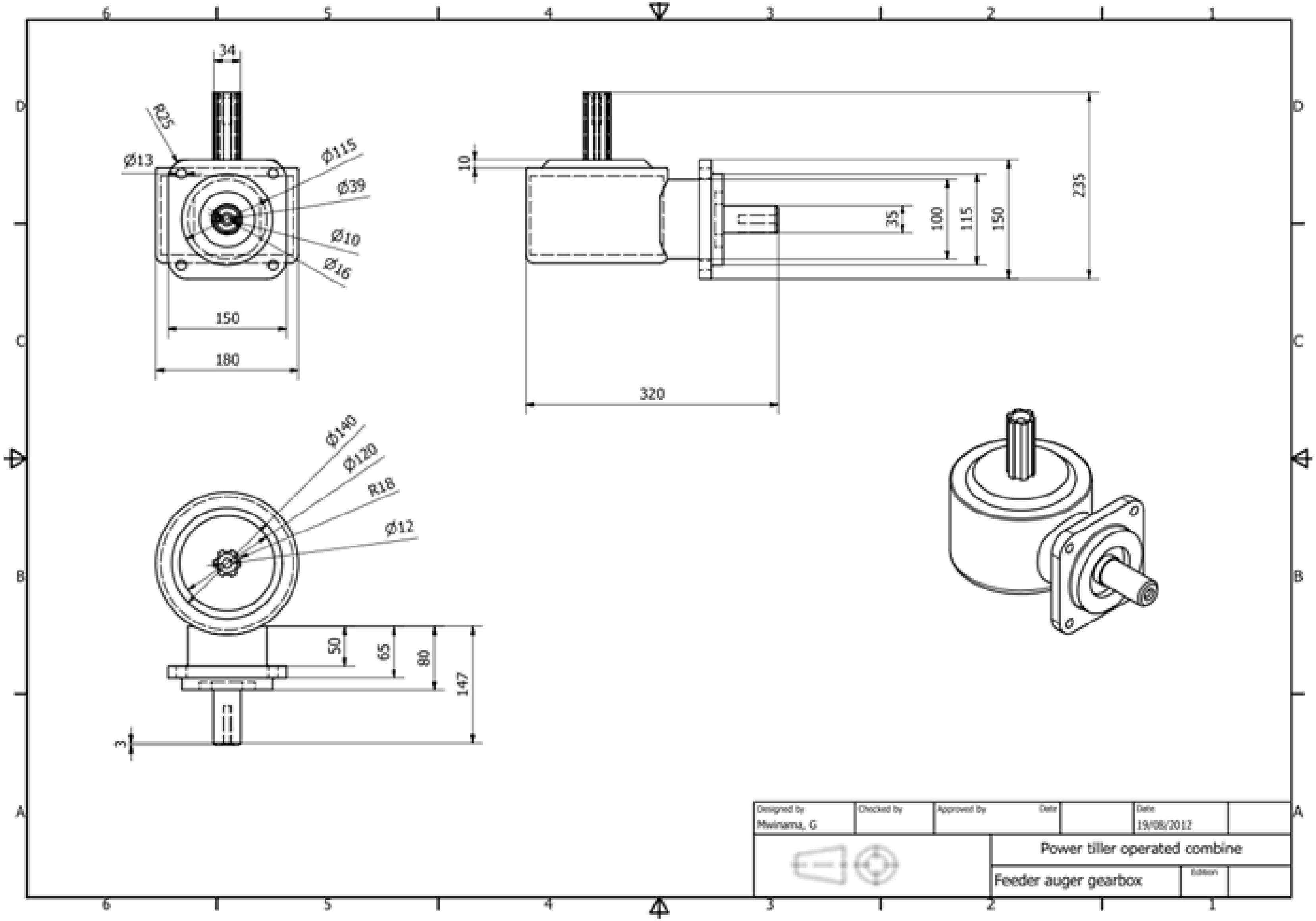


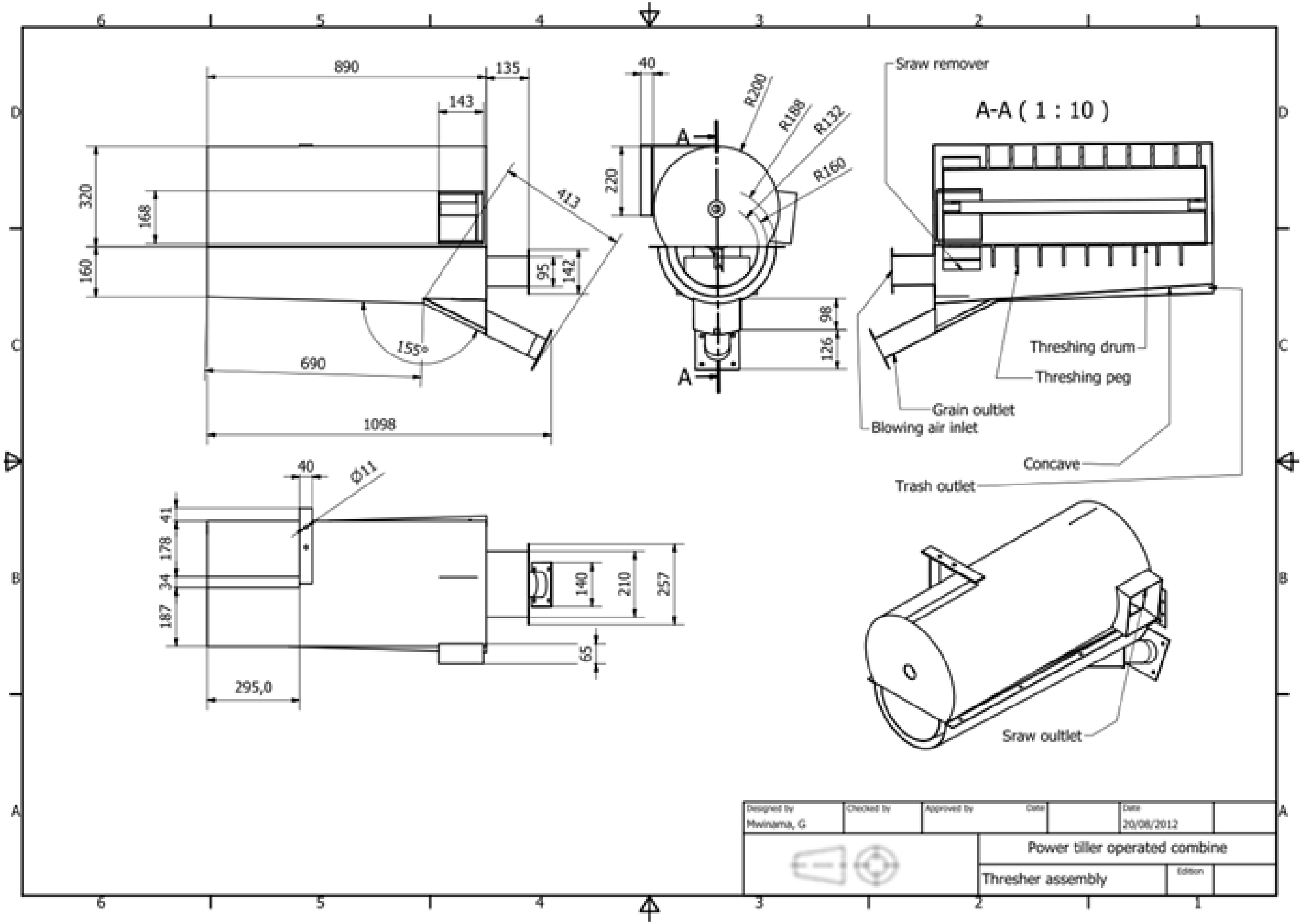
NOTE: Hood is made of 1.2 mm thick mild steel plate
1350
1410
R348
619
649
200
6.5 mm holes for bloting the hood to the header auger though
Designed by
Mwimama, G
Checked by
Approved by
Date
Date
29/06/2012
Power tiller operated combine
Hood
Edition



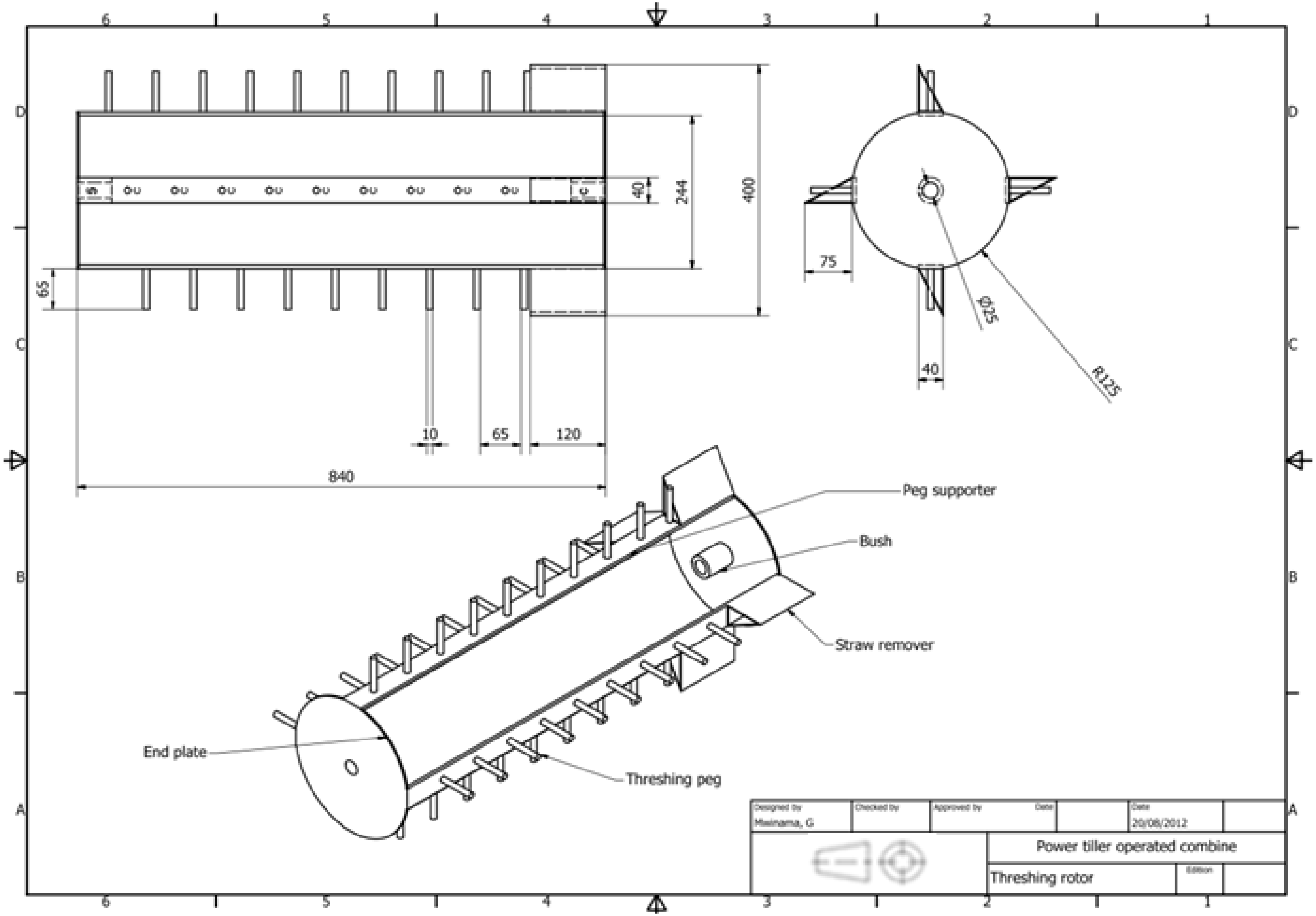
1397
65
R98
Ø25
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
19/08/2012
Power tiller operated rice combine
Feeder auger
Edition

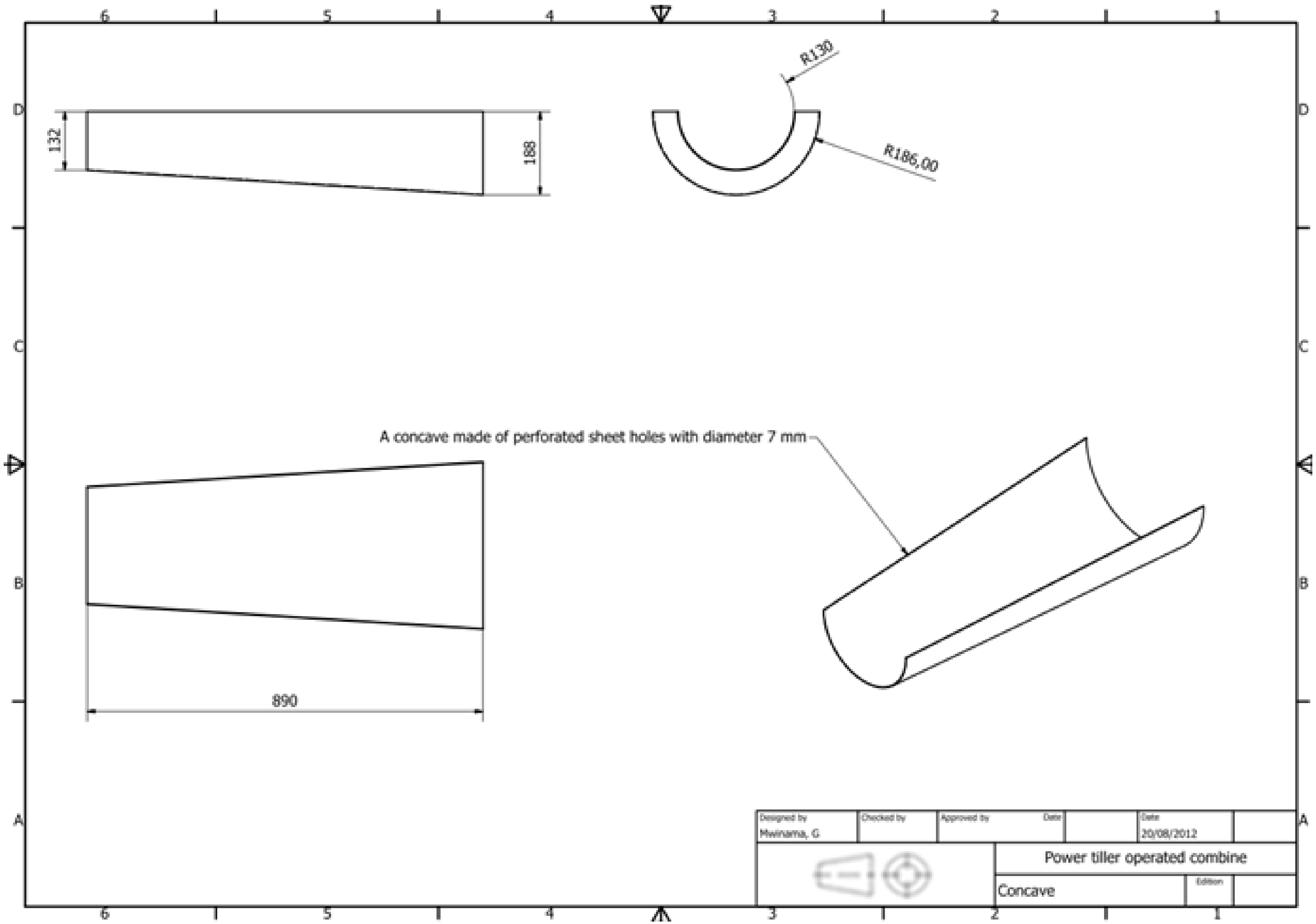

120
1080
250
106
169
159
68
55
86
164
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
19/08/2012
Power tiller operated rice combine
Feeder auger trough
Edition


34
R25
Ø13
Ø115
Ø39
Ø10
Ø16
150
180
10
35
100
115
150
235
320
Ø140
Ø120
R18
Ø12
50
65
80
147
3
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
19/08/2012
Power tiller operated combine
Feeder auger gearbox
Edition

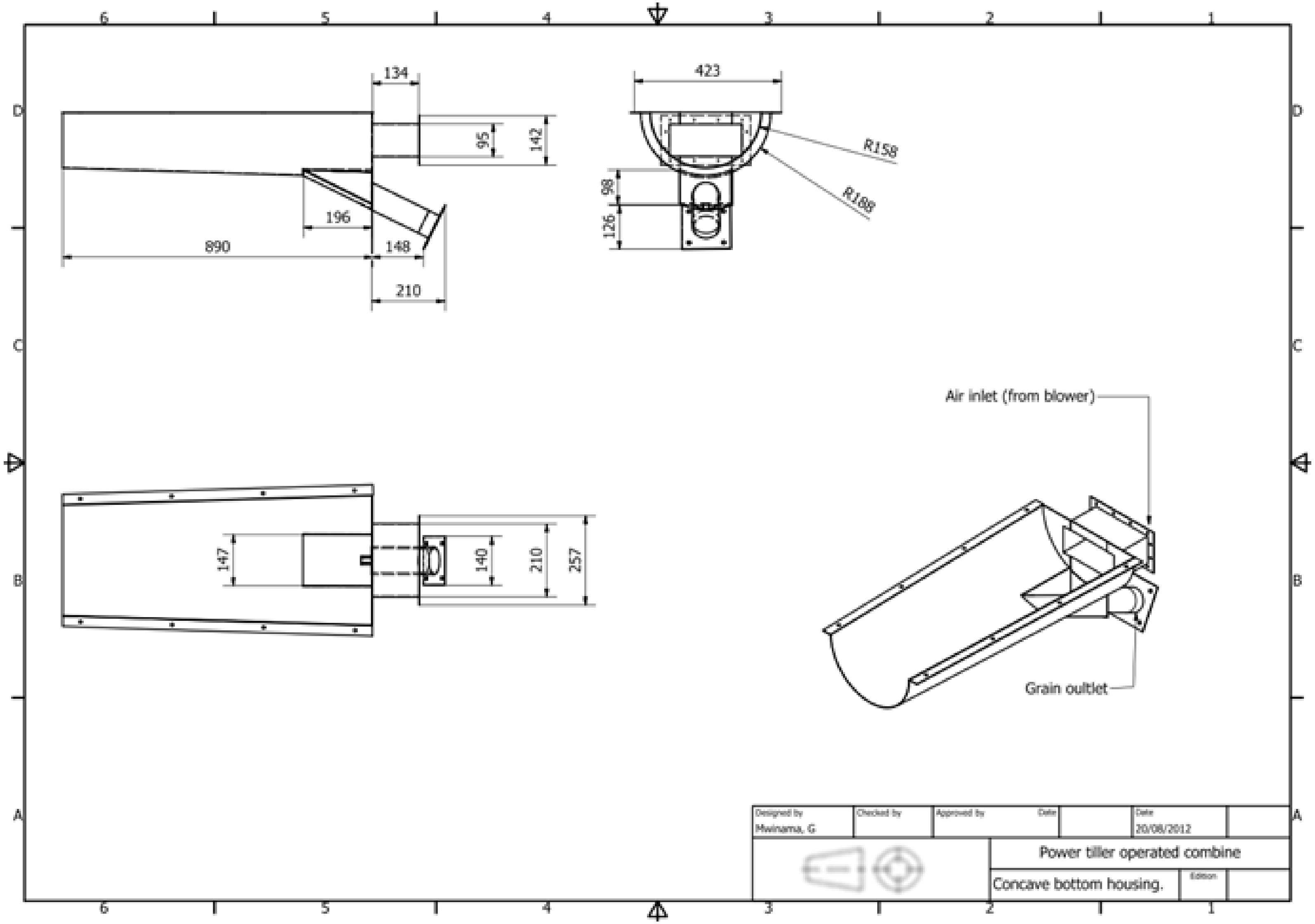


Sraw remover
A-A (1 : 10)
Threshing drum
Threshing peg
Grain oultlet
Blowing air inlet
Concave
Trash outlet
Sraw oultlet
Designed by
Mwinama, G
Checked by
Approved by
Date
20/08/2012
Power tiller operated combine
Thresher assembly
Edition

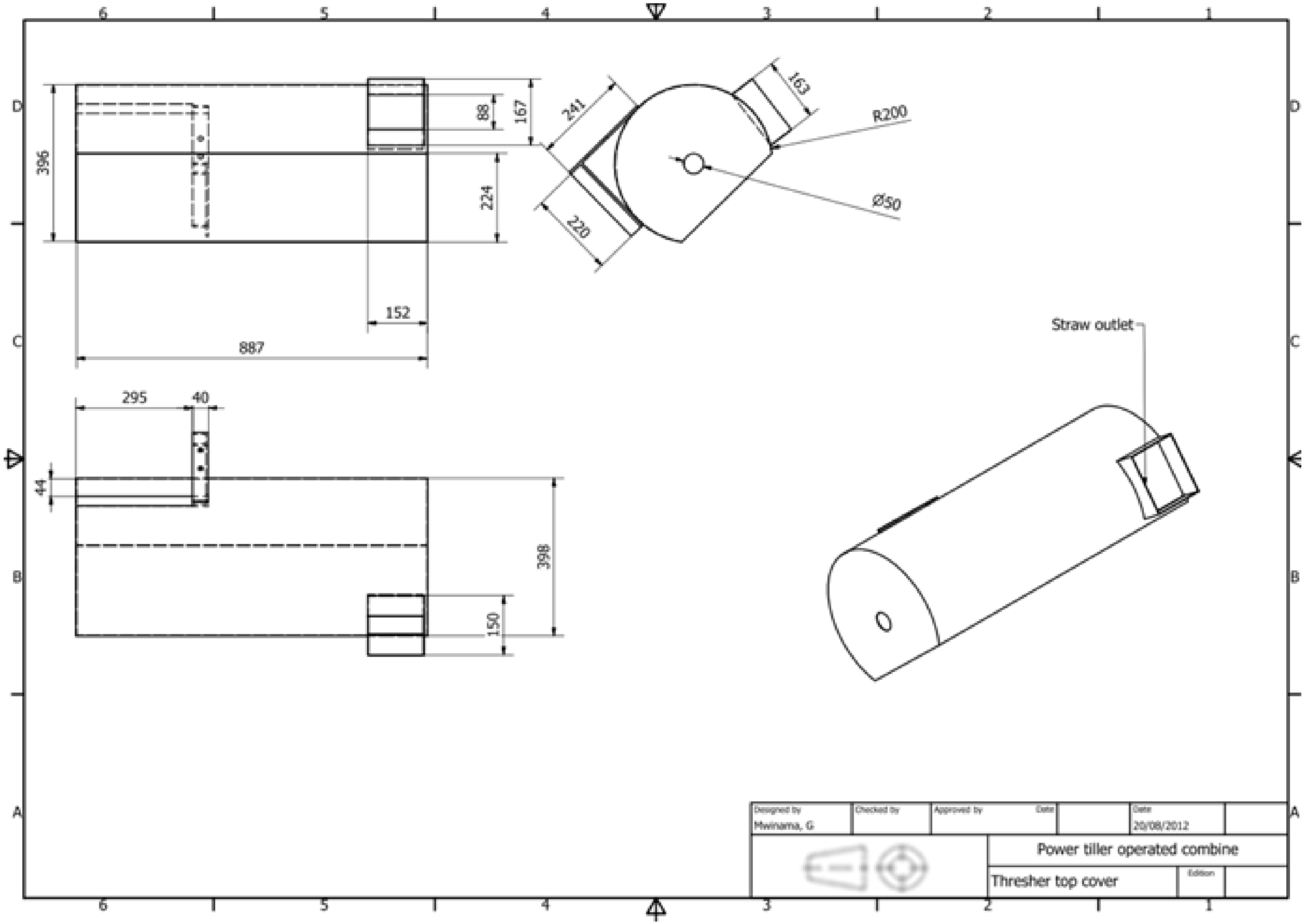

840
10
65
120
65
40
244
400
75
40
Ø25
R125
Peg supporter
Bush
Straw remover
End plate
Threshing peg
Designed by
Mwinama, G
Checked by
Approved by
Date
20/08/2012
Power tiller operated combine
Threshing rotor
Edition

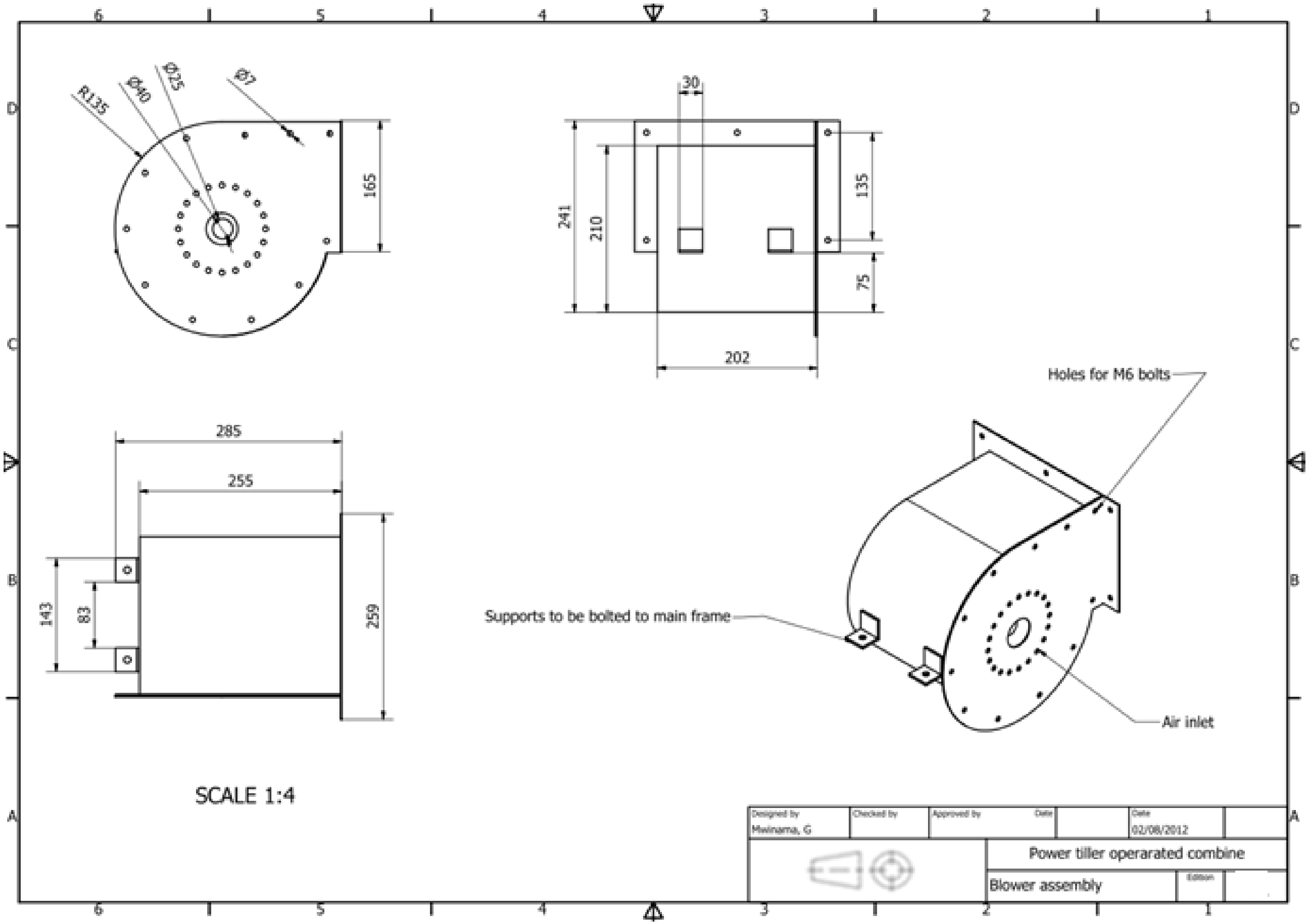


R130
R186,00
132
188
890
A concave made of perforated sheet holes with diameter 7 mm
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
20/08/2012
Power tiller operated combine
Concave
Edition

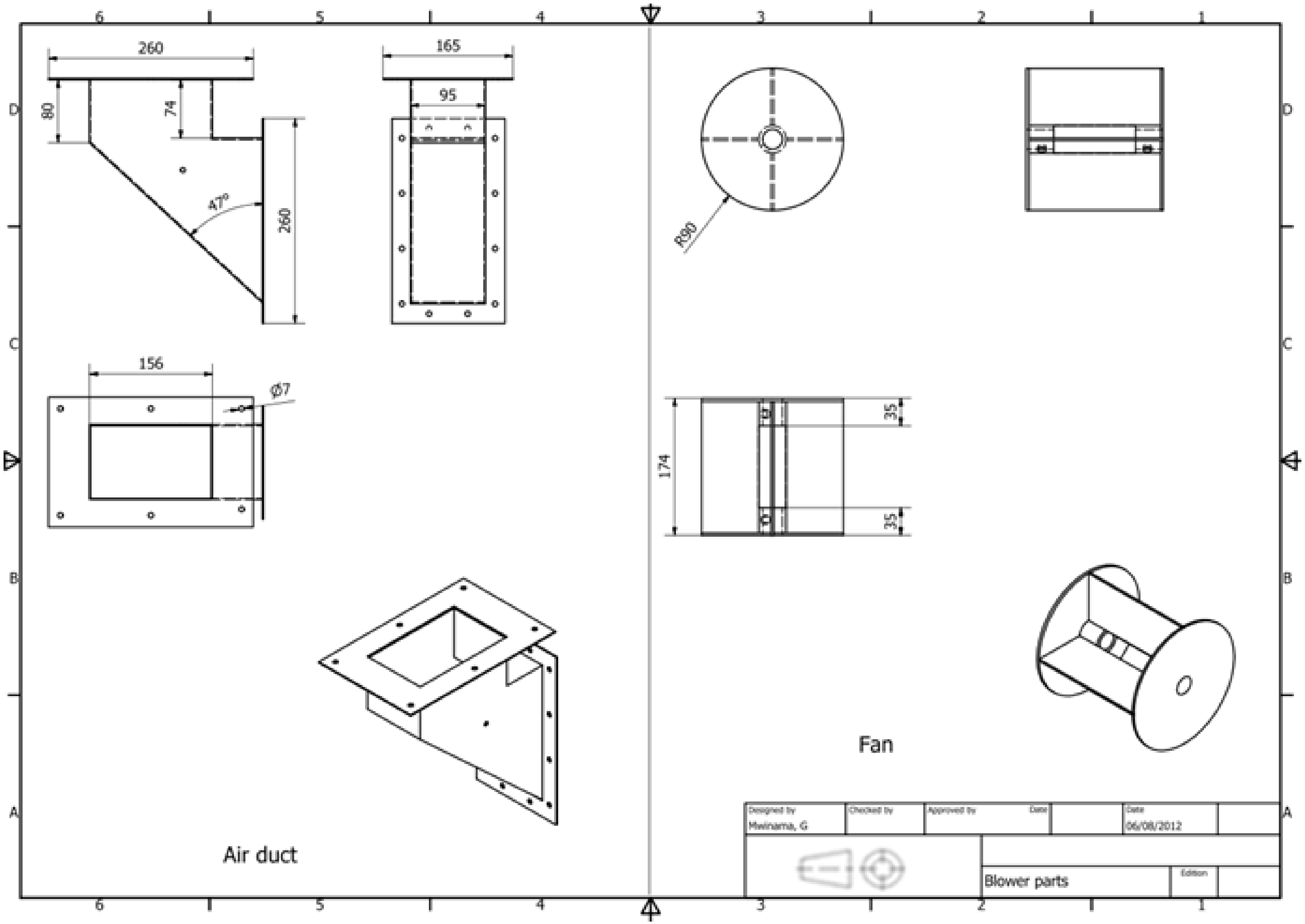


134
95
142
196
890
148
210
423
R158
R188
98
126
147
140
210
257
Air inlet (from blower)
Grain oultlet
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
20/08/2012
Power tiller operated combine
Concave bottom housing.
Edition

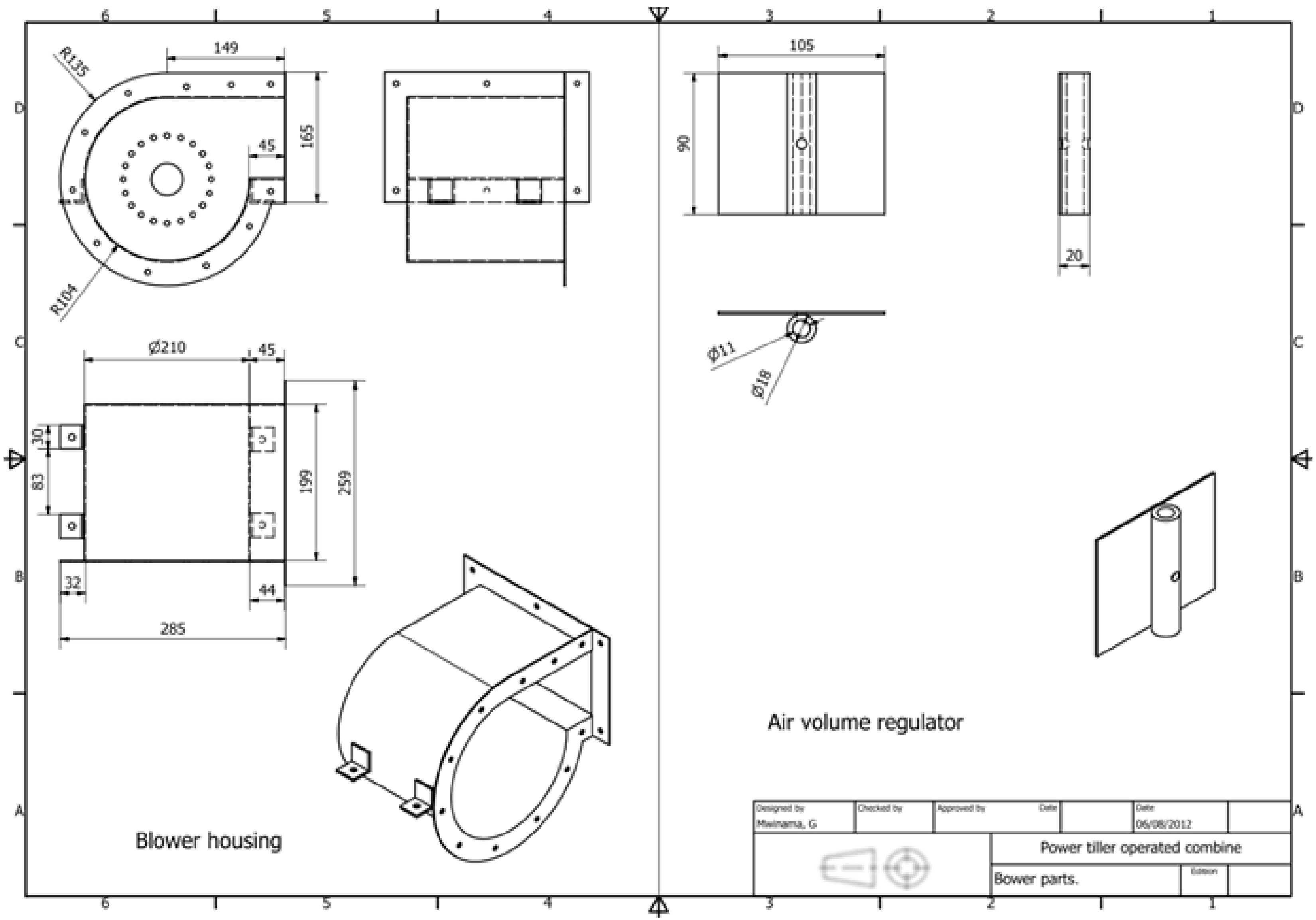

396
88
167
224
152
887
241
163
R200
Ø50
220
Straw outlet
295
40
44
398
150
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
20/08/2012
Power tiller operated combine
Thresher top cover
Edition

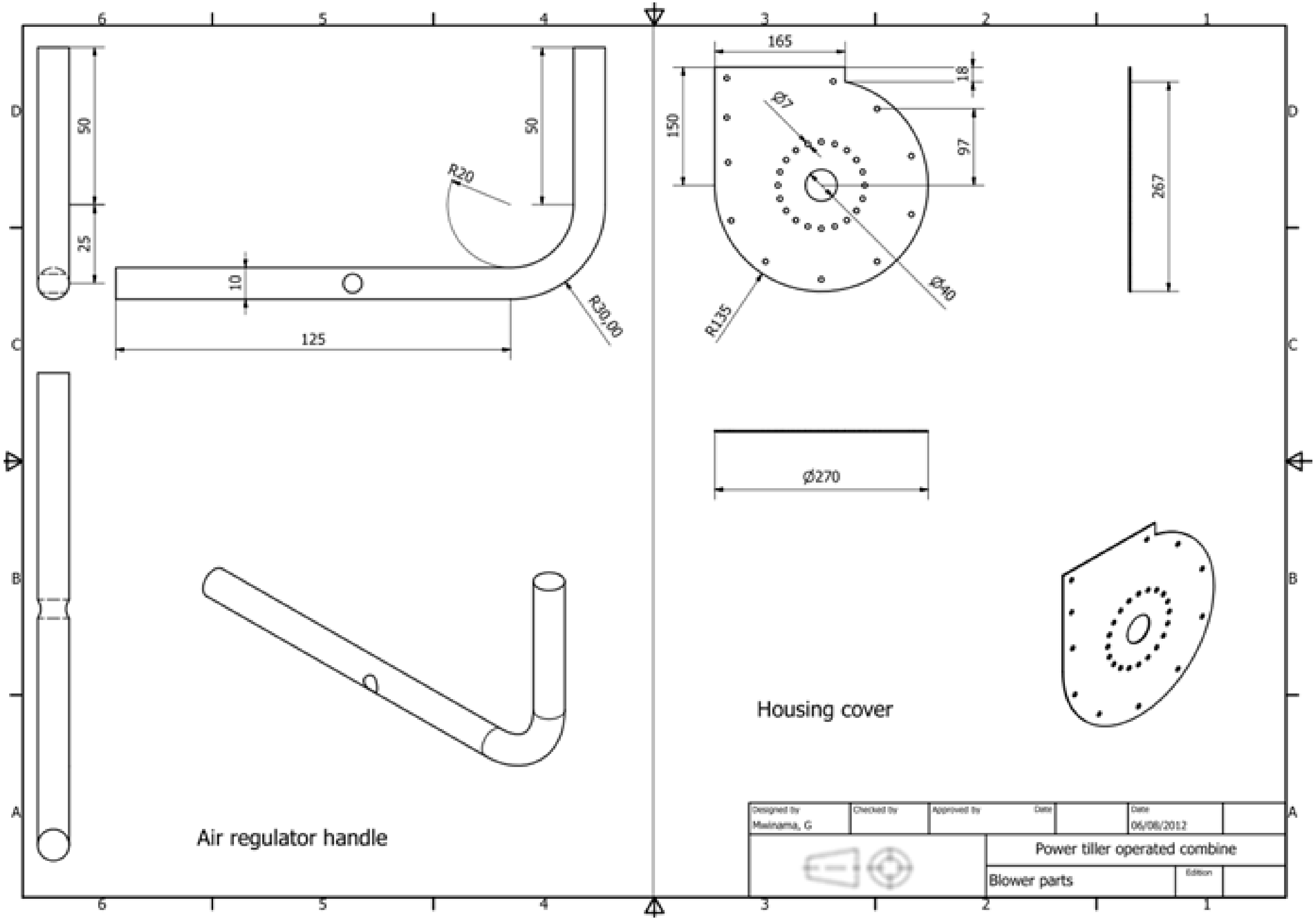


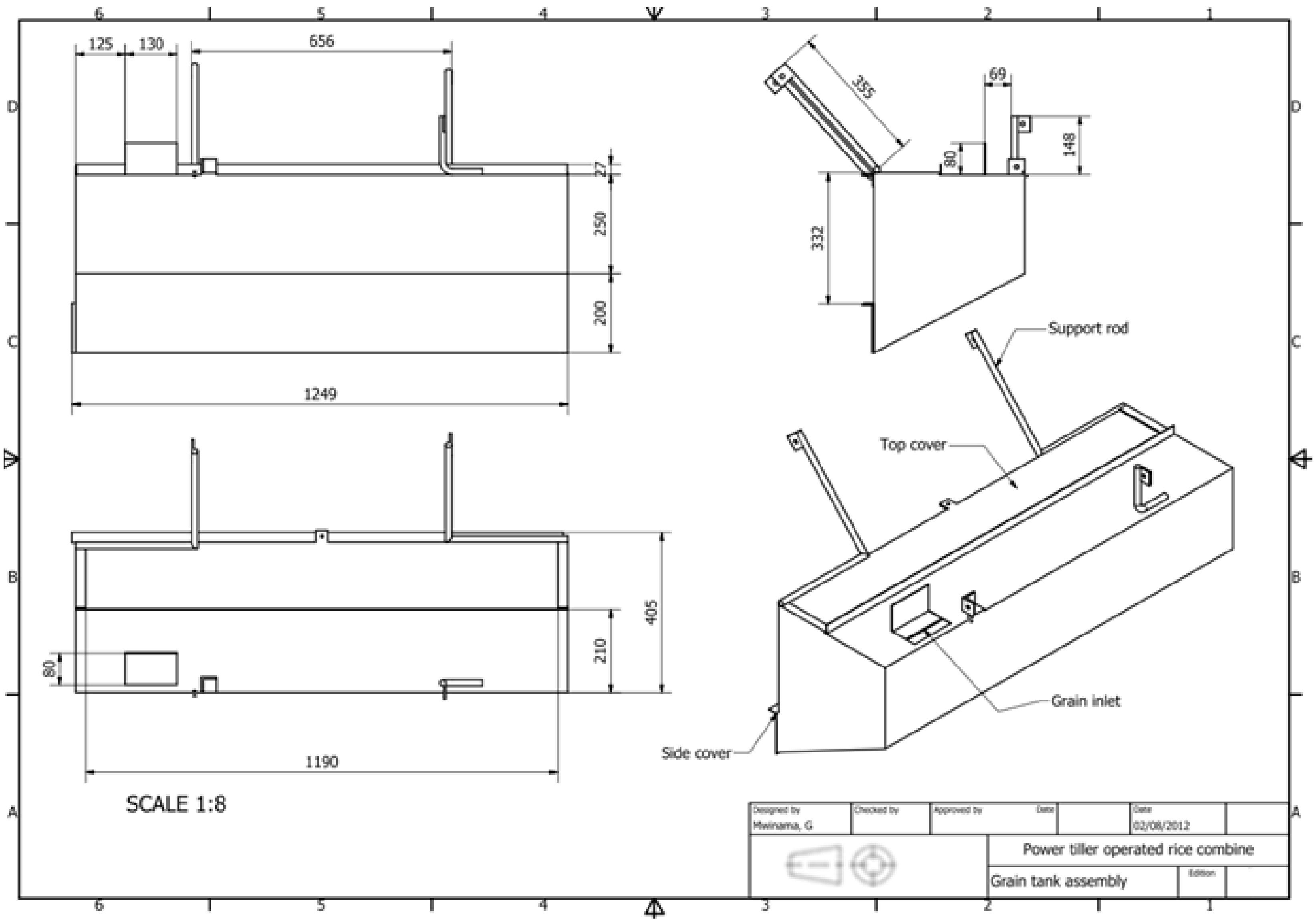
R135
Ø40
Ø25
Ø7
165
30
241
210
135
75
202
285
255
143
83
259
Holes for M6 bolts
Supports to be bolted to main frame
Air inlet
SCALE 1:4
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
02/08/2012
Power tiller operarated combine
Blower assembly
Edition

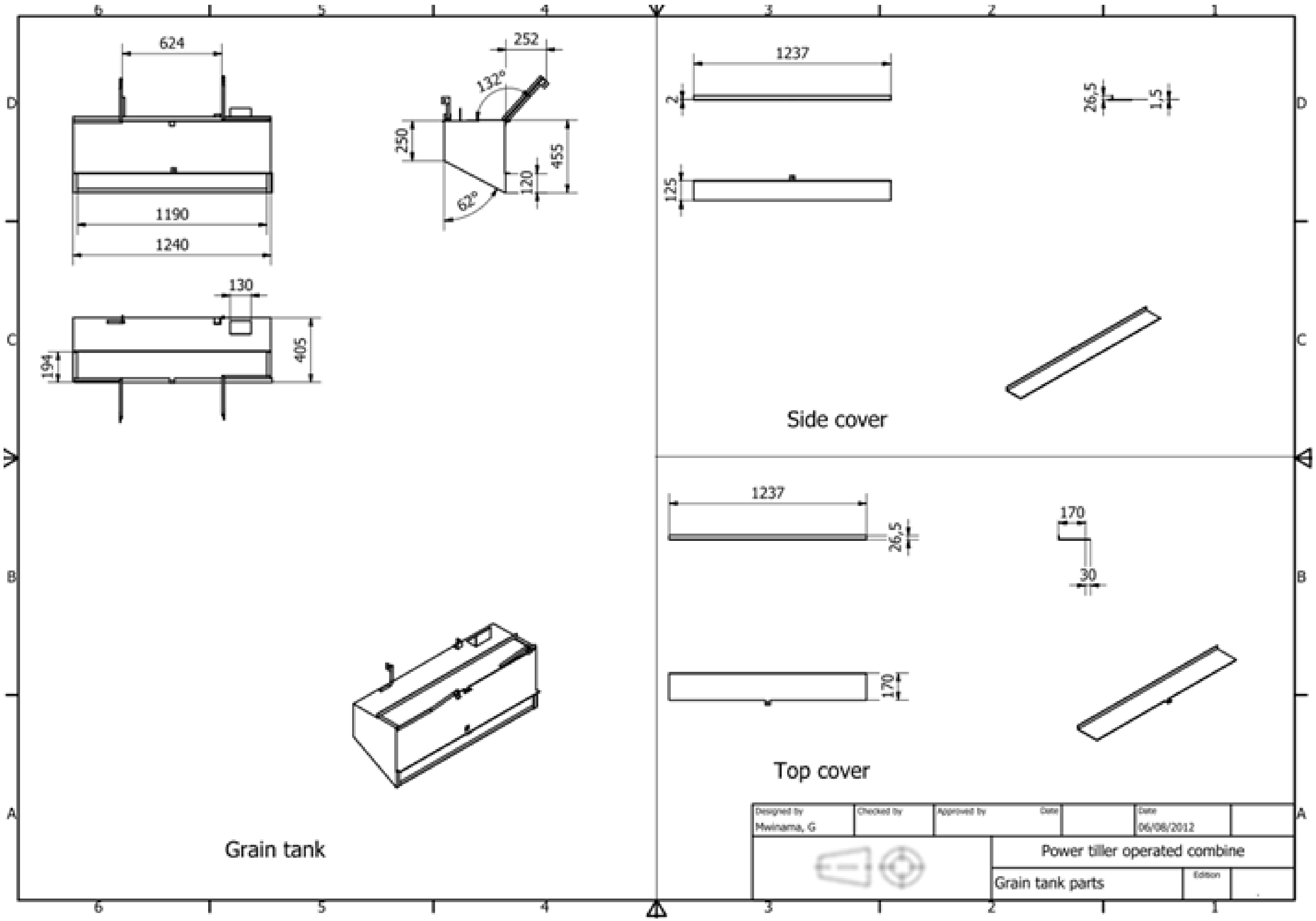


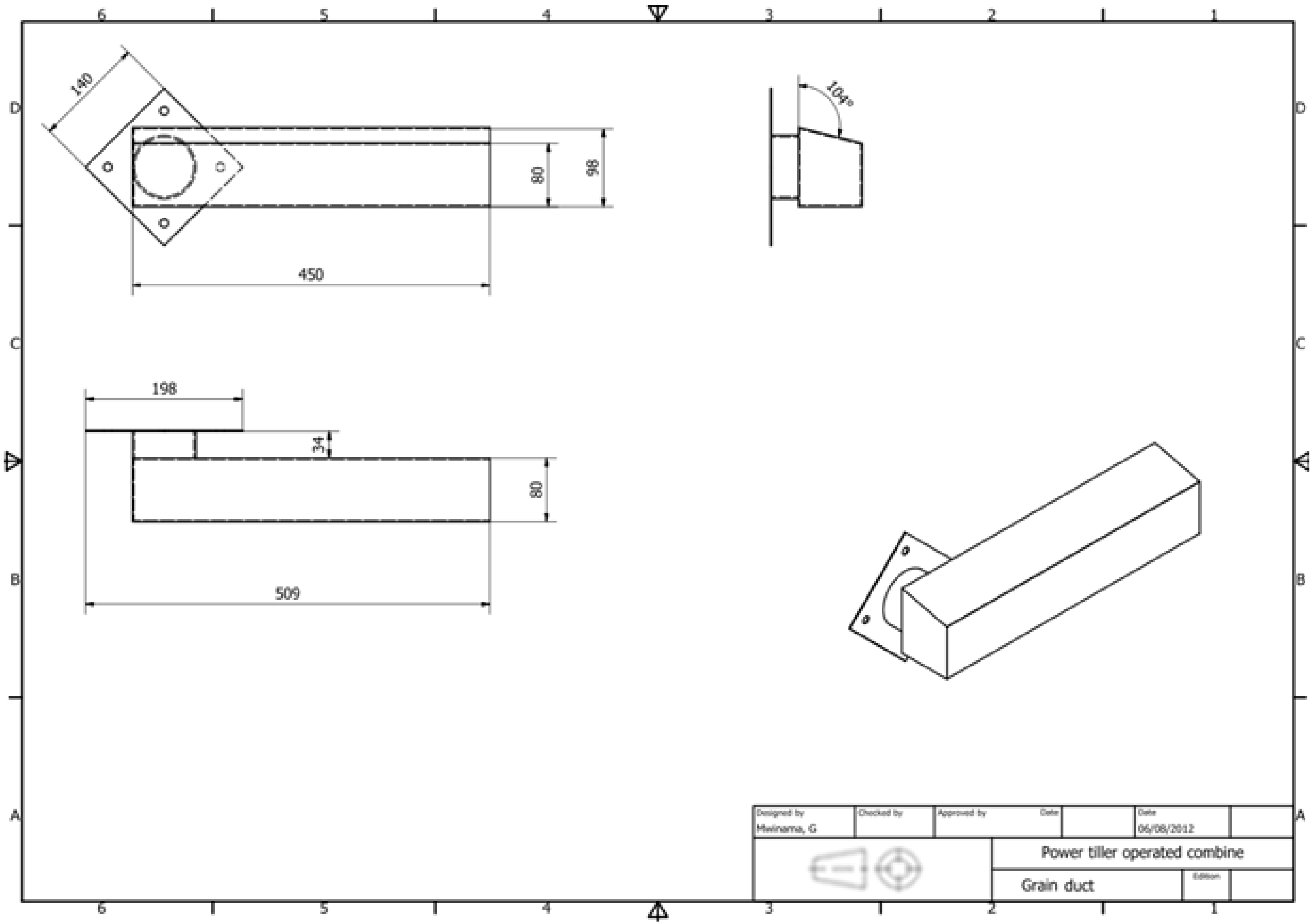
260
80
74
47°
260
165
95
156
Ø7
Air duct
R90
174
35
35
Fan
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
06/08/2012
Blower parts
Edition

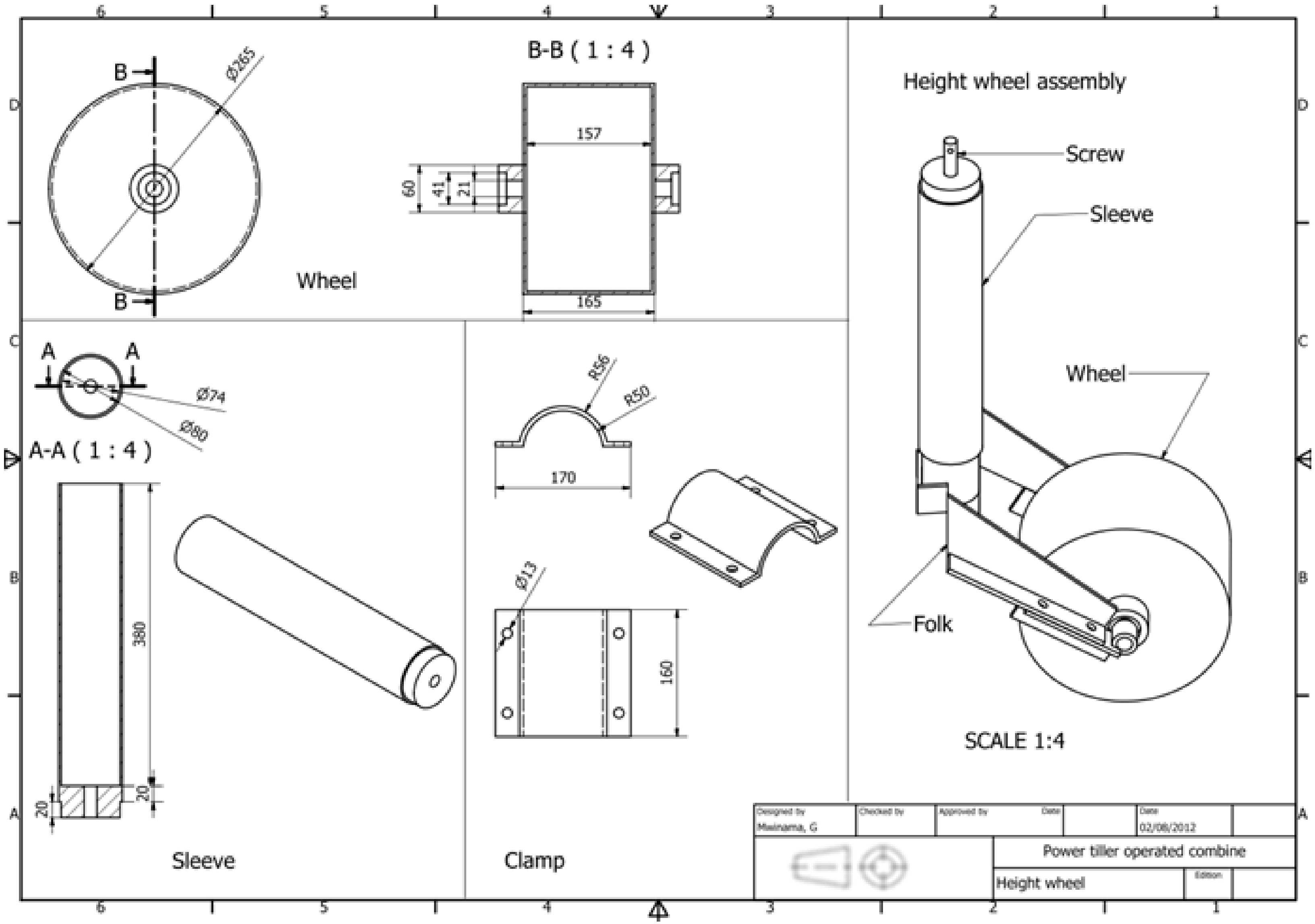

149
R135
165
45
R104
Ø210
45
30
83
199
259
32
44
285
Blower housing
105
90
20
Ø11
Ø18
Air volume regulator
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
06/08/2012
Power tiller operated combine
Bower parts.
Edition

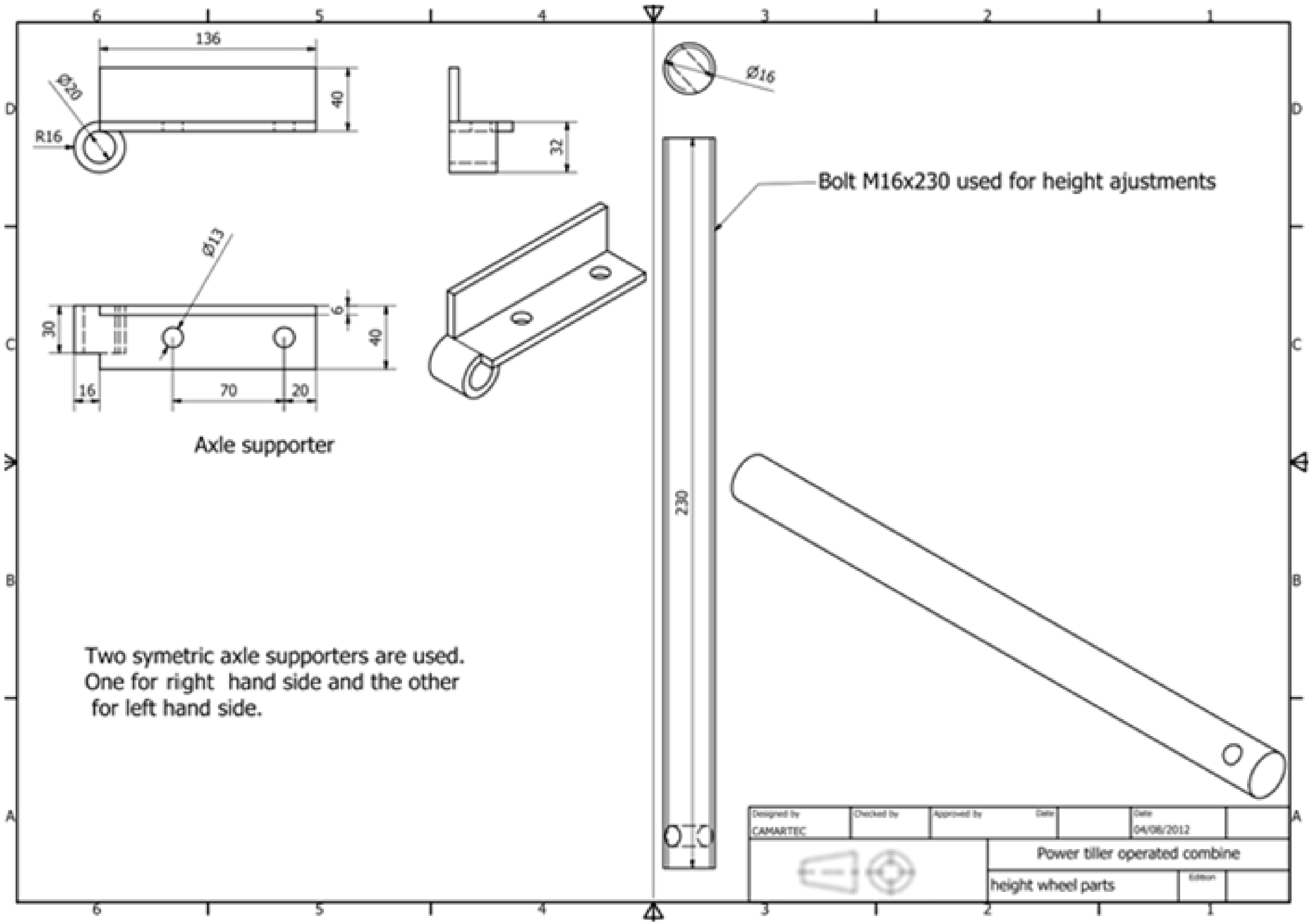

Air regulator handle
Housing cover
R20
R30,00
125
10
50
25
165
18
150
Ø7
97
Ø40
R135
267
Ø270
Designed by
Mwinama, G
Checked by
Approved by
Date
06/08/2012
Power tiller operated combine
Blower parts
Edition


125
130
656
1249
27
250
200
405
210
80
1190
SCALE 1:8
355
69
80
148
332
Support rod
Top cover
Grain inlet
Side cover
Designed by
Mwinama, G
Checked by
Approved by
Date
02/08/2012
Power tiller operated rice combine
Grain tank assembly
Edition


624
252
132°
250
455
120
62°
1190
1240
130
405
194
Grain tank
1237
2
26,5
1,5
125
Side cover
1237
26,5
170
30
170
Top cover
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
06/08/2012
Power tiller operated combine
Grain tank parts
Edition


140
80
98
450
104°
198
34
80
509
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
06/08/2012
Power tiller operated combine
Grain duct
Edition

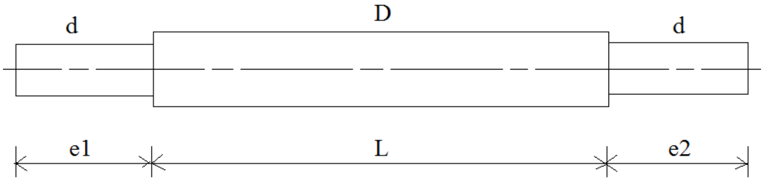

B-B (1 : 4)
Ø265
157
165
60
41
21
Wheel
A-A (1 : 4)
Ø74
Ø80
380
20
20
Sleeve
R56
R50
170
Ø13
160
Clamp
Height wheel assembly
Screw
Sleeve
Wheel
Folk
SCALE 1:4
Designed by
Mwinama, G
Checked by
Approved by
Date
Date
02/08/2012
Power tiller operated combine
Height wheel
Edition



136
Ø20
R16
40
32
Ø13
30
6
40
16
70
20
Axle supporter
Ø16
Bolt M16x230 used for height ajustments
230
Two symetric axle supporters are used.
One for right hand side and the other
for left hand side.
Designed by
CAMARTEC
Checked by
Approved by
Date
Date
04/08/2012
Power tiller operated combine
height wheel parts
Edition

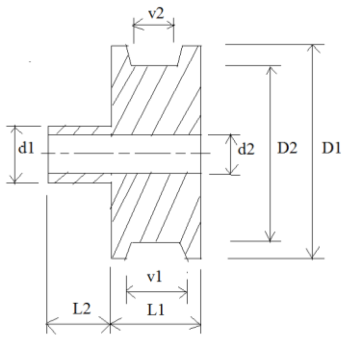
Appendix 4: Dimensions for PORCH shafts,pulleys and belts

a) Shafts dimensions for PORCH



Shaft name	Shaft dimensions (mm)				
	Lengths (mm)			Diameters (mm)	
	L	e1	e2	D	d
Front drive shaft	180	150	270	30	24.9
Rear drive shaft	310	145	125	30	24.9
Stripper gearbox drive shaft	195	220	125	30	24.9
Stripper gearbox driven shaft	195	40	175	30	25.9
Thresher shaft	1330	125	150	30	24.9
Blower shaft	210	40	155	30	24.9
Header auger shaft	1250	40	70	30	24.9
Stripper shaft	1250	40	90	30	24.9
Feeder auger shaft	50	1400	100	30	24.9

b) Pulley dimensions for PORCH



Pulley	**Dimensions (mm)**							
	D1	D2	d1	d2	L1	L2	v1	v2
Front drive shaft driven pulley	135	113	40	25	25	25	7	13
Stripper gearbox driving pulley (from front transmission shaft)	60	49	40	25	25	25	7	13
Header auger driving pulley (from front drive shaft)	60	49	40	25	25	25	7	13
Striper driving pulley (stripper gearbox driven pulley)	60	49	40	25	25	25	7	13
Rear transmission driven pulley	100	89	40	25	25	25	7	13
Thresher driving pulley (from rear transmission shaft)	210	199	40	25	25	25	7	13
Blower driving pulley (from thresher shaft)	260	249	40	25	25	25	7	13
Feeder auger gearbox driven pulley (from thresher shaft)	60	49	40	25	25	25	7	13

c) Belt and chain sizes for PORCH

Belt/chain position	**Type of drive system**	**Size**
From stripper gearbox to striper	Belt	A 41
Front transmission shaft to striper gearbox	Chain	31.5"
Front transmission shaft to header auger	Belt	A 49
Thresher shaft to feeder auger	Belt	B 34
Rear drive shaft to thresher	Belt	A 63
Thresher shaft to blower	Belt	A 53
Power tiller flywheel to front transmission	Belt	B 47
Power tiller clutch to rear drive	Belt	B 34

Appendix 5: Schematic table for PORCH drive system

Drive type	Location From	To	Input size	Output size	Transmission ratio
Belt	Power tiller flywheel pulley	Front drive shaft	135 (113)	170 (159)	0.71
Chain	Front drive shaft	Striper gearbox	60 (50) (16T)	60 (50)(16T)	1.00
Belt	Front drive shaft	Header auger	60 (49)	215 (204)	0.24
Gear	Front drive shaft	Stripper gearbox			2.31
Belt	Stripper gearbox	Stripping rotor	60 (49)	60 (49)	1.00
Belt	Power tiller clutch pulley	Rear drive shaft	235 (224)	170 (159)	1.41
Belt	Rear drive shaft	Thresher shaft	100 (89)	210 (199)	0.45
Belt	Thresher shaft	Feeder auger gearbox	60 (49)	100 (92)	0.53
Gear	Feeder auger gearbox	Feeder auger			2.5
Belt	Thresher shaft	Blower	260 (249)	60 (49)	5.1

Note: Values without brackets are outside diameters and those in brackets are effective inside diameters.

Transmission ration has been calculated as input effective diameter divided by output effective diameter. T represents the number of teeth.