DEVELOPMENT AND PERFORMANCE EVALUATION OF A PEDESTRIAN CONTROLLED RICE STRIPPER

BY

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DECEMBER, 2008

DECLARATION

I declare that the work in the dissertation entitled **"DEVELOPMENT AND PERFORMANCE EVALUATION OF A PEDESTRIAN-CONTROLLED RICE STRIPPER"** has been performed by me in the Department of Agricultural Engineering under the supervision of Dr. V.I.O. Ndirika, Prof. Y.D. Yiljep and Dr. U.S. Mohammed.

The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any University.

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CERTIFICATION

This dissertation entitled **"DEVELOPMENT AND PERFORMANCE EVALUATION OF A PEDESTRIAN-CONTROLLED RICE STRIPPER"** by Adisa, Alex Folami meets the regulations governing the award of the degree of Doctor of Philosophy, Agricultural Engineering of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This dissertation to the glory of God the Father, Son and Holy Spirit is dedicated to my beloved wife, Olubola Adisa and my wonderful children; Ayodele, Omolola, Abidemi, Afolarin and Ibukunoluwa.

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ABSTRACT

A pedestrian controlled rice stripper was then designed, fabricated and its performance was evaluated on a field with farro 44 variety of rice. The total estimated power required to operate the harvester was 2.33kw, while the stripping unit required only 0.78kw of the total power.

In evaluating the harvester's field performance, randomized complete block design (RCB) was adopted to study the effect of harvester's forward speed, stripper rotor speed, stripper rotor height, harvested grain purity, field capacity, fuel consumption and harvester efficiency.

Results showed that time taken had high significant effect at 1% level on the harvester's forward speed. The shattered loss showed both linear and polynomial trend of increase as the harvester's forward speed increases. The stubble loss increases linearly and polynomially as both stripper rotor speed and harvester's forward speed increases. Lodging losses also increased both linearly and polynomially as the stripper rotor speed and harvester forward speed increases at two levels of rotor heights 270mm and 220mm.

The time taken to harvest had high significant effect at 1% level on the harvester forward speed, at two levels of the rotor heights. Also the

fuel consumption decreased in a polynomial trend as the stripper rotor speed increased at the two levels of rotor heights 270mm and 220mm.

At stripper rotor height 270mm, harvester forward speed of 3km/h and stripper rotor speed of 670rpm gave the lowest total losses. These combinations gave shattered loss as 5.46%, stubble loss 4.97% and lodging loss 3.08% of the total yield at 270mm rotor height. Also the effective field capacities was 0.078 ha/h; and fuel consumption was 27.6 litres/ha, the harvester's efficiency at the same settings was 81 percent and grain purity was 90.3% at the same machine settings.

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ABBREVIATIONS AND SYMBOLS

A = Area, m^2

C_a = Belt angle contact factor

C_m = Belt length factor

C_{tg} = Total grain stripped, kg

D_f = Degree of freedom

E = Young modulus of elasticity, MN/m^2

EFC = Effective field capacity, ha/h

F_B = Tangential force, N

fc = Coefficient of belt friction

Fc = Bearing operational or service factor

fe = Bearing equivalent radial force, N

Fe = Field efficiency, %

F_m = Fuel consumed, L/plot

F_p = Draw bar pull, Kw

F_r = Bearing resultant force, N

Fs = Factor of safety

F_t = Bearing thrust force, N

g = Acceleration due to gravity, m/s^2

G_p = Grain purity, %

H = Thrust, Kw

H_e = Harvester efficiency, %

K = Belt dynamic load and service factor

K_d = Drive tension factor for V-belt

K_m = Shock and fatigue factor on bending moment

K_t = Shock and fatigue factor on torsional moment

L_g = Lodged loss, %

n = Speed, rpm

P = Power, Kw

P_c = Concentrated load, KN

P_d = Power at the ground drive, Kw

P_e = Effective engine power, Kw

P_g = Power loss in gear box and speed reduction box, Kw

P_L = Power loss to slope, Kw

P_r = Power loss in rolling resistance, Kw

P_s = Power loss in wheel slip, Kw

P_t = Draw bar power plus other useful power, Kw

R = Stripper rotor height, mm

R^2 = coefficient of multiple determination

Rr = Rolling resistance

R_{Bh} = Horizontal bending moment component, Nm

R_{BV} = Vertical bending moment component, Nm

S_c = cracked grains, %

S_L = Shattered loss, %

Ss = Allowable shear stress, N/M^2

S_t = Stubble loss, %

T	=	Torque, Nm
T_L	=	Total loss, %
T_t	=	Time taken, seconds
Ty	=	Total yield, kg
U	=	Harvester forward speed, km/h
V	=	stripper rotor speed, rpm
ω	=	angular speed, radians/second
τ	=	Shear stress, N/m^2
σ	=	tensile stress, N/m^2
α	=	Contact angle, degree
θ	=	Angle, degree
β	=	Sheave groove angle, degree
μ	=	Net traction coefficient
μ_g	=	Gross coefficient of traction
ρ	=	motion resistance ratio
η	=	Harvester efficiency, %

CHAPTER ONE

1 INTRODUCTION

1.1 Background Information

Rice has become a staple food in Nigeria homes for quite some time now and the local supply, 38% is found to be far below the demand [Oputa *et al.,* 1985) and hence effort is to be directed towards increasing the product quantity and quality. Most of Nigeria farmers practise mixed cropping like interplanting rice with row of maize or sorghum or millet or cowpea (Ladipo and Ajobo, 1986).

Rice harvesting requires cutting of the matured head, threshing, cleaning and bagging. With mechanical means, it is not as tedious as when done manually. Apart from the intensive labour involved, losses are encountered at various stages of harvesting and processing which is usually higher with manual than mechanical methods of harvesting.

Different crops require different labour type and power requirement for harvesting, however there is need to design a harvester for our small rice fields and also for the interplanted rice fields. This must be simple in structure, high working efficiency and adaptable to our farming system. The design will be an alternative to manual harvesting meant for small farm size. The machine in mind will strip heads alone and fabricate with available local materials. The standing stripped straw can be cut for other usage or be plowed into the soil.

1.2 Nutritional and Industrial Importance of Rice

Rice meal and Rice bran can be produced from Rice i.e cow-bran produced from hulling paddy is low food value. Then bran or meal produced in the pearling process comprises the pericarp, alerurone layer, embryo and some of the endosperm which contains most of the vitamins and proteins of the grain which is of high food value.

Rice bran contains a percentage of lipids which are about 14% to 17% oil of which 3% to 9% is wax which can both be extracted.

Rice is mainly used as a food, being boiled or steamed and eaten with meat, fish and vegetables. It has also many other uses in food and commerce. In 1930 it was estimated that 86.5% Japanese rice produced was for food, 5.2% for making wines, 4.9% for cakes, 1.2% for seed, 1.1% for sugar and smaller amount for salted bean paste, soya sauce and vinegar and for starch. It is also been made use of in various forms as a medicine in general throughout Asia (Grist, 1986).

1.3 Rice Production and Consumption

Rice is grown in regions of Asia, Africa, central and south America and Australia. About 90% of southern East Asia land area is devoted to rice cultivation. There are only two cultivated species, Oryza glaberrima steud and oryza sativa linn. Oryza glaberrima is confined to West Africa as upland crop but replaced with oryza sativa (Grist, 1986).

Oryza glaberrima is relatively grown in some small areas in West

Africa. Oryza sativa is widely grown in tropical and sub-tropical regions, either as a dryland (upland) crop but more usually in water (fadama). The ripe seed is the staple food in many Eastern countries.

Oloruntoba et al (2007) reported that United Nations General Assembly (NUGA) declared the year 2004 as the International Year of Rice (IYR). This was because rice has become primary food source for more than half of the World's Population (Fresco, 2003; FAO, 2003). Rice is essential for food security, poverty alleviation and improves livelihood (The Comet, 2002).

In sub-Saharan Africa, Nigeria is the second largest importer of rice and also ranked ninth in the world as reported by IITA (1994). The local demand as at 2005 was put at 5 million metric tones while the domestic supply was 3.2 million metric tones leaving a deficit of 1.8 million metric tones. Oloruntoba (2007) also reported that the Federal Government of Nigeria launched as of June 2005, the New Rice for Africa (NERICA) which was aimed at increasing local production and contributes to food security and import substitution. The primary policy actions directed towards increasing productivity and income of rice farmers and to remove main barriers preventing the transformation of small-scale farmers to modern farmers who will make use of productive technology and credit facilities available (Balogun, 1998).

Four factors are responsible for rice demand which are population growth, current levels of income and expected increase in real income,

elasticity of rice demand (Oputa et al., 1985). This provides the relationship between changing incomes and changing purchase of rice and expected price increase compared to substitute for food. The population increase (2.6%) with the remarkable shift in the dietary behaviour mostly increase the domestic demand for rice far beyond local supply level giving way to massive importation, resulting in great price increase (Oputa et al, 1985).

1.4 Statement of Problem

Nigeria agriculture is characterized by fragmented small size of farm holdings ranging between one and two hectares. This is due to non availability of farmland in a single location. Also some farmers practices mixed cropping which require each crop to be independently harvested (Ladipo and Ajobo 1986). Majority of our farmers have poor financial background which limits them from purchasing modern farm machinery. On small farms, the bulk of the farm produce is needed for family food supply while the remaining surplus is sold for small amount of money (Subair, 1986).

Rice farming in a system as stated above is generally in small scale and are predominantly cultivated manually from planting to post harvesting. Up to 40% of the total cultivation input is expended on harvesting, hence there is need for mechanical harvesting to reduce operational cost, time, harvest losses and improve grain quality

(Carruthers, 1985). Harvest losses, like front or header, threshing and cleaning/separation losses pose great problem in the agricultural production and any machinery developed for harvesting must have objective of reducing the harvest losses to the minimum value (Ferreira et al, 2001).

Over 75% of farmland in Nigeria today are put under cereals production which are subjected to changes in cropping practise from place to place within the country, aimed at bringing the supply of food into better balance with consumption (Oputa et al, 1985). Pressure has been increasing rapidly to raise the quality of farm produce and at the same time to reduce inputs because of the cost of these inputs and rapid population growth, the food demand of which we are to meet. Losses and waste will need to be curbed even more than in the past at harvesting and post harvesting stages, and fewer men and more cost effective methods and machines will be required to reduce the adverse effect the high inflation is having on labour and machinery costs (Ferreira, 2001). This provides an opportunity for objective analysis of the efficiency, cost effectiveness of the few machines in the system that *are* presently in use and the locally manufactured alternatives which could replace at least some of them (Patel, 1989). The possibility of design simplification needs to be put in mind constantly, and greater sophistication should be limited mainly to applications which can substantially increase cost effectiveness, safety and suitable for our small scale farming system

(Oputa et al., 1985).

Some considerations were taken into account in the development of the in situ seed stripping concept at the Institute of Engineering Research (IER), England (1987). The basic idea of grain stripping is centuries old and in more recent times static and rotary comb systems have been marketed. But none have been developed to performance levels which would make them commercially acceptable under the crop and climate conditions in Europe and some other countries. Major short comings of past grain stripping header developed as at 1987 were high shatter losses caused by crop disturbance, incomplete grain detachment, failure to collect detached grains, blockages of essential crop aligning or stripping components, and inability to harvest tangled and lodged crops satisfactorily (Klinner, 1987).

Based on average Nigerian farmer small farm size holdings, low technical skill and per capital income can not afford them to own existing medium to large size harvesters available in the market. The recent development of the combine harvesters to improve it performance, increased capacity and reduced harvesting losses have made it highly sophisticated. Also it is now too big in size for normal highway road traffic, too heavy that easily causes soil compaction and very costly beyond ordinary farmers reach, Klinner et al (1987). This now require researchers to look into other alternative design concept that will meet this machine performance need at lower cost, small size and less

sophistication.

1.5 Justification

The production of a rice stripper harvester which is of a simple technology will not only reduce the drudgery involved in rice harvesting but will encourage farmers to increase their hectarage because it is reported to be one of the major rice production limiting factors. Local production of the rice stripping machine will make it readily available and at relatively low price. This will save the country some hard earned foreign exchange. It will also increase rice production to back up the Federal Government's self sufficiency in food production and total ban of rice importation policies. Also, it will engage many people, especially youths in rice production and increase job opportunities in the rural areas.

However, the design and construction of this type of machine should be simple without involving any complex production method and should not require the use of sophisticated production machine, and instruments. This will not only ease the machine production operation but also its repair and maintenance with readily available spare parts at affordable prices.

1.6 Objectives of the Study

The general objective of this research work is to design, fabricate

and produce a pedestrian controlled rice stripper harvester.

The specific objectives are:

1) To determine the design related physical properties/characteristics of rice crop varieties.
2) To design and fabricate rice stripping header.
3) To evaluate the prototype machine at different farming field conditions
4) To compare the machine performance with existing manual rice harvesting method.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Different Types of Cereal Crop Harvesters

Crop harvesting equipment available to small farmers mostly in the developing countries has not received adequate improvement over the years. Knives, Sickles and Scythes, Figure 2.1, continue to be the traditional tools used to harvest crops (Stout and Cheze, 1999). In the past, some reapers with low power rating were developed, but because of their low field capacity, high cost and other problems, they were usually not considered suitable alternatives to the manual methods. On the other hand, a large number of efficient, low-cost hand, foot or power driven threshers have been developed for use on small farms Worldwide (Carruthers, 1985).

2.2 Mechanized Farming in Nigeria

Farm mechanization is designed to meet one or more of the following purposes (Subair, 1986).

- To increase crop yields
- To increase cropping intensity
- Expand the area of cultivated land
- Improve cropping patterns
- Improve the quality and value of farm products
- Decrease farm costs
- Overcome labour shortages

It can be said therefore, that the main reasons for farm mechanization varies from country to country and region to region. In highly industrialized countries, the main motive for mechanization may probably be due to acute shortage of farm labour. On the other hand, this motivation will not exist in a country in which there is little or no industrial development, and where labour resources are readily available to meet agricultural demands (Subair, 1986).

It is observed that Nigeria's small scale farming system is made of small holding which uses family labour for most operations, occasional hired labour especially during planting and harvesting and use of traditional implements (Ladipo and Ajobo, 1986). We can classify Nigeria as a Nation of small farmers since the pattern of agriculture is predominantly subsistence, based on mixed farming and bush fallow to allow soil refertilization. From these small holders come over 90% of the nation's food, fiber and export crops (Ladipo and Ajobo, 1986). The existing poverty associated with the agricultural sector results from the primitive nature of the production system and farming technology which consists of hoes and machetes with the attendant low productivity and hence low income. The low income of small holder producers is one of the factors responsible for the low level of technology in under developed countries. They have low farm resources, limited non-farm opportunities, low level of formal education, below average management abilities and are usually late or non-adopters of technology (Ladipo and Ajobo, 1986).

First consideration should be given to the use of machinery which is locally made and can be maintained at low cost; complementary with resources of labour and power availability on the farm.

2.3 Rice Physiology

The roots of paddy- whether grown as a dryland crop or in water are much branched and posses a profusion of root hairs. Paddy is referred to the land on which the plant is grown and also to the unhusked seed. Husked or milled rice is referred to as brown rice which can be milled to remove the outer layers of aleurone and germ and polished referred to as white rice. Except the deep water type, ultimate height of rice is about 1m plus and can be as short as 0.5m for dwarf varieties. It is now a well established fact that rice varieties suitable for heavy fertilization usually have shorter culms and greater ability to tiller than plants with long culms. **Height of rice plant** is an important trait, being related to the **harvest index**, growth duration, nitrogen response and lodging resistance (Chang and Lu, 1980). Rice tillering which has direct influence on crop yield is influenced by cultural conditions, spacing of plants amount of nitrogen fertilizer applied, weeds and water supply. That is, the effect of nitrogen application on grain yield is largely attributed to the increase in number of panicles which, inturn, is governed by the number of effective tillers (IRRI, 1967).

2.3.1 Lodging

Rice lodging may be the result of environmental conditions e.g wind, shade, diseases, temperature etc. (external factors) or may be specific to the variety e.g height, late maturity, stalk strength etc (internal factors). This is another **harvesting index factor** that affects mechanical crop harvesting (Chang and Lu, 1980).

2.3.2 Maturation period

Maturation period depends on whether the variety is season or date fixed. Indica variety is photosensitive and therefore date fixed while Japonica is photo insensitive and therefore not date fixed. The maturation period may be anything between 90 and 260 days and within limits, maturation period varies with environmental and climatic conditions. The ripening phase from flowering stage to harvest is that the panicle weight increases rapidly while straw weight decreases. The ripe grains turn from green colour to golden yellow, when moisture content is between 27% to 15%, it will be ready for harvesting. Shattering is premature shedding of grain from panicle which has considerable differences in tendency between cultivated varieties but depend largely on the conformation of the joint between the pedicel and the rachilla, i.e the point at which ripe grain disarticulates (IRRI, 1967).

2.3.3 Rice physiology related to machine design

All rice sub-species and varieties in Nigeria are annuals growing 80-125cm tall at maturity stage (Oputa et al, 1985). The nature and form

of the root system that develop, depends on whether the seed is sown under wet or dry conditions but both have enough root/soil holding capacity (thick and profuse root system) for stripping header.

Characteristic feature of rice plant (Oputa et al., 1985) are:

- Thick and profuse root system.
- Short and stiff culm
- Thick small and erect leaves
- High tillering capacity and
- Well exerpted and compact pancile

Paddy rice varieties are tightly encased by layers of husk that is high in siliceous material so also the straw which are highly abrasive. Therefore selected header grain handling components are to be made of stainless steel, alloys or abrasive resistant coatings (Stout and Cheze, 1999).

2.4 Physical and Mechanical Properties of Rice

The rice grain is spherical in shape and its longest side is measured as its length, the middle sides are the width and the thickness (Grist, 1986). Rice grains are arranged on the stalk head. The rice grains, straws and leaves surfaces are high in silica hence abrasive in nature. The crop height at maturity varies from varieties to varieties. The rice root formation is profuse in nature which has high soil/root holding capacity.

2.5 Design Related Information for Rice Harvester

The following design related information's were established by Klinner et al (1987) for the development of rice harvester:

1. 360^0 stripping of plant stems could be achieved
2. Provided adequate rotor speeds were used, seed detachment from the stems was good. With correct setting, there was no tendency for the rotor to become wrapped or to uproot crop.
3. Matters other than grain (MOG i.e. blanks, stems, weed seed and etc) varied from 50%
4. Tighter concave settings were needed for stripped material
5. Basic principle of the new stripping system is a high speed, overshot combing mechanism, which was covered by a curved hood with height-adjustable front section.
6. Vertical hood clearance above rotor bottom depth center of 300-370mm gives minimum head losses. While the horizontal hood to rotor clearance was of 90mm.
7. In cereals, a rotor tip speed of 18 to 22m/s gave the required efficiency of dislodging the grain from the heads and recovering it.
8. Power required at no-load consumption was found to be 0.8kw/m while at work the power requirement per meter of rotor width was 2.29 kw/m.
9. The resistance of crops to uprooting is sufficient to permit removal

of seeds by in-situ stripping, provided the speeds and settings of the rotary con-mechanism are matched to crops and conditions.

10. Matching forward speed with rotor speed is important for an efficient stripping header.

2.6 Grain Losses in Crop Harvesting

The losses in crop harvesting can be categorized into pre-harvest loss, cutter bar loss or front header loss, threshing loss in the threshing unit due to grain breakage etc and cleaning loss or straw walker or separation loss due to grain lost with chaff, straw etc in combine harvester (Culpin (1981). The value of these losses varies from crop to crop and from equipment to equipment. But the acceptable harvest losses range from 0 to 5% of the total yield for rice and other cereal crops, Riethmuller (2001). Manual harvesting results in higher grain losses which usually have direct contact with soil particles that result into poorer grain quality than combine harvested grain apart from the drudgery involved in the manual harvesting, Carruthers (1985).

2.7 Energy Required for Release of Grain from Ear

Energy required to release grain from the ear is an important agrophysical parameter, it knowledge can play a role both in the classification of cereals and in breeding new varieties. Also in consideration of new harvest technologies, reduction of losses during

harvest and finally in an energy analysis of the employed methods of threshing, Reznicek, (1971). The insitu stripping mechanism employed for this stripper header may directly benefit from measuring this mechanical work required for extracting grain from the ear if appropriate apparatus, tensile testing micro machine is available from which power can be obtained. From Reznicek (1971) findings, the minimum energy W_e required for releasing a grain mass unit can be employed.

$W_e = N\overline{K}_c \overline{l} \overline{F}_b = \frac{1}{M_a} \overline{K}_c \overline{l} \overline{F}_b$ .....(2.1) where, W_e = minimum energy required

$\overline{K}_c, \overline{l}, \overline{F}_b$ *are mean values*

N = Number of grains per Kg, = $1/M_a$

M_a = Average mass of grain, kg

K_c = Coefficient expressing course line of binding force

l = grain length

F_b = maximum binding force of grain to ear.

α = grain angle between the stalk

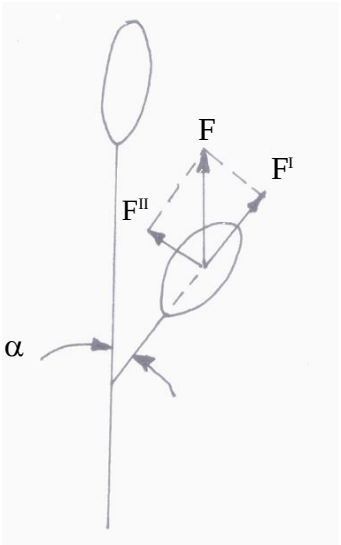


Figure 2.2: Grains located laterally experiencing pullout force component.

This can be used to serve for assessing the energy balance for stripping but may not actually be exactly the same since it may be more relevant to asses minimum energy required for releasing 1kg grain during threshing from the ear as reported by Reznicek (1971) and

Ndirika (1997), see figure 2.2.

2.8 Research and Development Efforts on Rice Stripper Headers

The study of past works done on different types of stripper header reveals the following:

(a) Kilgour's (1991) work on stripper harvester's performance was rated technically high most especially in crops like wheat and barley that are planted in concentrated position. The MOG intake was found to be 50% of that of conventional combine and recovered 1.4t/ha of grains more than conventional harvester. He came up with the following suggestions for further improvement on the stripper machine:

- Should be able to work effectively on crops where products are not concentrated in one position (broadcast).
- Compare it's performance with crops like rice and soyabeans.
- How it could fit in a viable economic way.

(b) International Rice Research Institute (IRRI, 1990) developed a stripper header of 0.6m width that was found profitable to harvest 13ha/year of rice, with the header losses of 2.3% of the total yield and required 40% cost of the manual harvesting. Further development needed (Douthwaite and Quick, 1990) are:

- Incorporate a rethresher/straw separator for small and light machine retain.
- Better maneuverability in small field parcels.
- To develop crop dividers that will work efficiently in broadcast

and lodged crop.

(c) Shenyang Agricultural University, China observed on the wheat stripper header for interridged field of wheat and corn crops (Yulai et al, 1999) are:

The 0.6m width self propelled harvester was able to harvest interridged field crops of wheat and corn and its clean rate was 85% and 0.253ha/h field capacity.

- Overall losses rate is theoretical (3%) which is within the scope of acceptable but there is practical problem of consumer acceptance
- Only one worker is needed to operate the combine harvesting but operator is restricted by operating environment and need a better comfortable operating condition.

(d) Tado (2003) and Jiang (2003) gave the following suggestions for further improvement on the stripper header after tracing the development of pedestrian-controlled stripper harvesters in the Philippines:

- Improve on energy requirement and noise level.
- Further evaluate the adaptability of the machine under various field conditions.
- Improve on settings of critical operating parameters.
- Further improvements on the effective machine performance on the country side.

To also design a harvester that is light and more compact to overcome excessive weight problem.

(e). Elegbeleye et al, (2003) worked on a tractor mounted header with rotor speeds 100, 140, 180, 220 and 260 rpm and forward speeds 3 and 5km/h. They recorded decrease in header losses with speed increase. There is therefore the need to work on wider speed range on their research study.

CHAPTER THREE

3. THEORETICAL CONSIDERATIONS AND DESIGN OF MACHINE COMPONENT PARTS

3.1 Description and Working Principles of Rice Stripper

Grain stripping rotor unit detaches grain from stalk which have to overcome detachment force that depends on the crop stalk and grain moisture content, thickness of the stalk at point of detachment, maturity stage of crop, condition of detaching mechanism and other factors. The diameter of rotor unit is 50cm and 30cm wide for rice row, spot and broadcasting planted with eight of the stripping elements mounted on the rotor drum. The rotor height can be varied from 30cm to 20cm height above the ground while the rotor speed of 400rpm, to 800rpm can be obtained by selecting appropriate pulley and belt sizes

The auger conveyor is 30cm long and 5cm pitch and diameter which is housed at the lower backward end of the grain box. It is to discharge the stripped materials from grain box at 150rpm.

Furrow divider was made of 6cm wide by 0.3cm thick flat iron bar and protruding ahead of stripping rotor unit by 20cm. It is part of means to reduce stripper poor performance in having clear separation between stripped row and unstripped row.

Dislodging mechanism was incorporated to dislodge the lodged crop. This was made of three L shaped hooks of 0.8cm diameter and 30cm x 10cm hanging on the front end of hood nose ahead of stripping

unit.

Clutch was made of idler belt and pulley tension type for power transmission to stripper rotor, screw auger conveyor and machine forward movement from 3.71kw (5hp) petrol engine through series of pulleys and belts.

The machine traction unit was made of two front 350mm diameter rubber tyres and one rear articulated tyre connected directly to the T pipe steering unit. The grain box was made of Gage 1.8mm metal sheet of size 50cmx30cmx34 cm (0.051m^3) volume capacity with bottom plate at angle 30^0. Assembly and components drawings of the rice stripper are contained in Appendix E.

This stripping harvester was developed as an alternative to manual harvesting for small scale rice farmers. The stripping comb-like (8) resilent elements are mounted horizontally on an upward rotating drum which engages crop stalks as machine advances forward. This comb-like element was made of slender finger with keyhole-shaped recess slots between each pair of teeth root of 12mm diameter. The hole detaches ears and grains at high speed from the straw and throws the materials removed back into the crop boxes which are later discharged out through auger conveyor for further rethreshing. See stripping operation in figure 3.1.

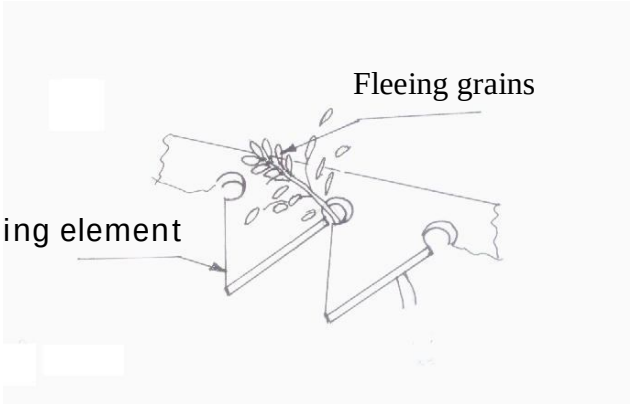


Figure 3.1: Stripping operation.

3.2 Design Considerations and Assumptions

The following were the design considerations and assumptions for this stripper machine design:

- The forward speed of the machine must be within human walking speed range since it is a pedestrian-controlled machine.
- The stripper rotor speed must be within speed range that will be able to strip the rice head at 360^0 without uprooting the crop itself.
- The driving shaft sizes and materials must be able to withstand the combined torsion and bending moment based on maximum shear theory.
- The total weight of the machine must be within the range of 80kg to 100kg for the effective powering by a 3.71kw petrol engine.

- The rice handling component parts of the machine must be of abrasive resistant material

3.2.1 Furrow divider

One of the major problems that can affect stripper performance is poor furrow divider between operation rows. The furrow divider is very important and it is made of wide flat bar protruding ahead of stripping rotor unit as shown in Appendix E.

3.2.2 Stripper front hood

Nose of stripper front height of 100mm below plant height and hood inlet clearance of 40mm has already been found satisfactory by Tado and Quick (2003) in their work on the machine. This machine is designed and set at that specification since the stripped materials is mainly grains with little chaff intake. See Appendix E.

3.2.3 Dislodging mechanism

Rice crop can grow to a height of 1m and above with slender stalk, it is therefore subjected to lodging by wind and rain storm towards the age of maturity. The need to incorporate a dislodging mechanism is very important for the machine to be able to stripe the whole grains on the crop in the field. This is made of three L shaped hooks hanging on the hood nose ahead of the stripping unit which is to dislodge the crop and assist in lifting it for stripping. See Appendix E for dislodging mechanism.

3.3 Design Calculations

Based on the above design considerations and assumptions, the machine component parts were designed as follows.

3.3.1 General power transmission to functional units

The power transmission from an engine to the other machinery moving parts to perform various functions for field work can be traced out in the layout diagram below:

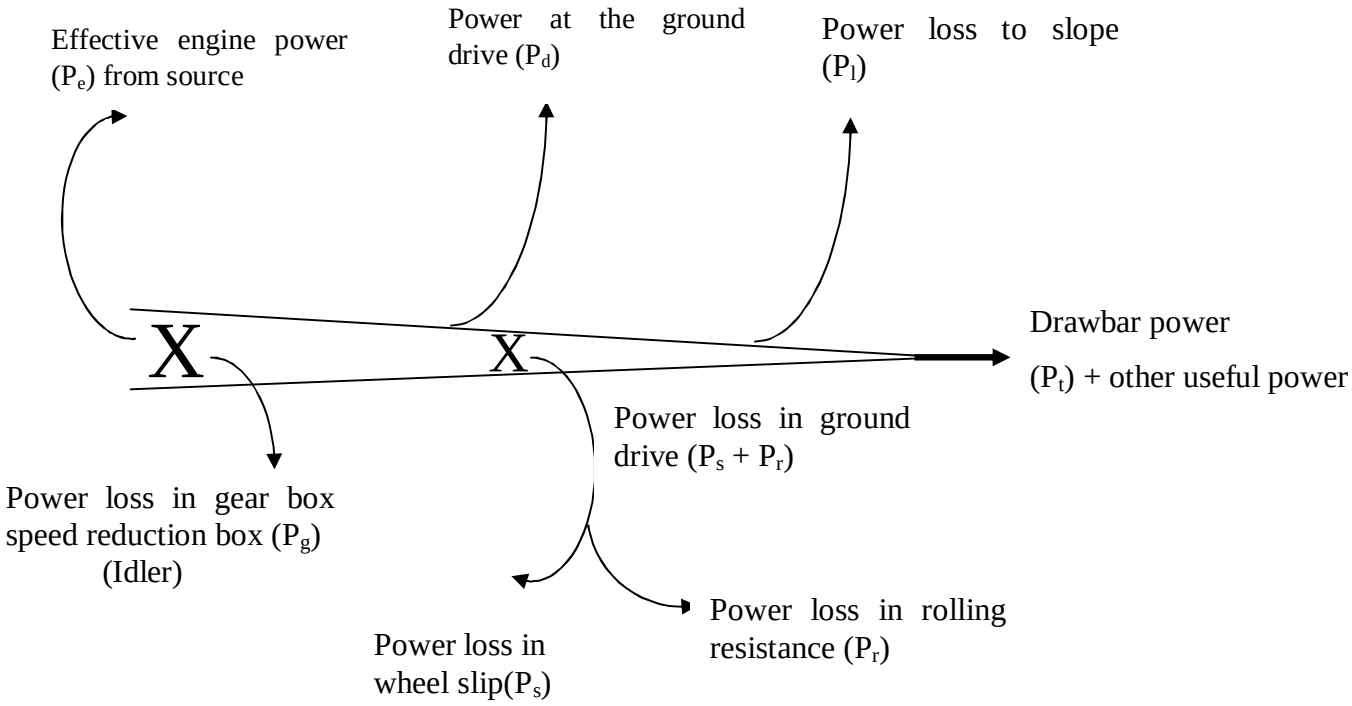


Figure 3.2: Power input and output relationship for an agricultural tractor (equipment), Inns 1985).

Then $P_e = P_g + P_s + P_r + P_l + P_t$ .....(3.1)

Also $P_e = P_g + P_d$ .....(3.2)

Where $P_d = P_s + P_r + P_l + P_t$ .....(3.3)

The draw bar power (P_t) is power for pulling a given load at minimum wheel slip. For a self propelled machine, the breakdown of

draw bar and other power required to operate this machine system can further be expressed as:

i. Moving machine over the ground

ii. Powering the machinery components (draw bar power) for useful work which include:

    a. Power loss within transmission system

    b. Combining or stripping grain

    c. Conveying grain (auger conveyor).

    d. Power to overcome ground slope

    e. Threshing grain

    f. Cleaning grain

Take note that this stripper header development will not include crop processing i.e. items (e) threshing grain and (f) cleaning grain.

3.3.2 Design calculation for machinery power requirement

At the beginning of this machinery design work, the following assumed data were used and both the design and construction parameter were based on them, most of which were obtained from the machine size/capacity and materials for construction.

- Total weight of combine harvester on full load = 80kg
- The weight on the front drive wheels = 45kg
- The weight on the rear driven wheel = 35kg
- Forward speed of the machine (average), ω = 3.9km/hr (10.5 rad/s)
- The radius of the drive front wheel = 0.17m

- The 5 h.p (3.71kw) petrol engine assumed could produce maximum torque of 1.4kgm at 2,800 r.p.m. (Appendix A, figure A1)

1. Torque required to drive the machine,

T = force x force arm..... (3.4}

$$= \frac{45}{1000} \text{ X } 9.81 \text{ x } 0.17 = 0.075\text{kNm}$$

2. Forward thrust (H) on the machine should overcome:

- rolling resistance (R_r)
- Provide draw bar pull (F_p)
- Overcome the down hill component of machinery weight on a land of maximum slope 3^0(5.2%).

Also the speed of the engine rotation was converted into forward travel speed of the machine.

Hence forward thrust, H = Tω --- (3.5), H= 0.075 x 10.5 = 0.787kw

Below are the two methods used to estimate machine gross power requirement.

The forward thrust is equivalent to ground drive with expected efficiency (GDE) of 70% (Krutz, et al., 1984), then the expected forward thrust (ground drive). See Appendix A, figure A2 pull slip predictor chart.

$$= \frac{0.787}{0.7} = 1.12\text{kw}$$

3.3.3 Power required by each machine rotating component parts

a. **Rotor stripping unit**

Maximum weight of rotor assembly with stripped materials = 6kg

Maximum rotor tip speed of 18m/s, ω = 685r.p.m (72rad/s)

Rotor diameter = 0.5m

Torque required to operate rotor from equation 3.4= 14.7Nm

Power required by stripping rotor from equation 3.5= 1.06kw

b. **Grain handling unit (Auger Conveyor)**

Maximum weight of conveyor with stripped materials = 5kg

Diameter of auger = 10cm

Speed of conveyor = 200r.p.m (21rad/s)

Power to drive conveyor = 0.05kw

Total draw bar power required, P_t = (a) + (b) = 1.11kw

c. **Power required to overcome ground slope (P_l)**

Total weight of machine plus grain = 80kg

Maximum expected ground slope = 3^0 (5.2%)

Force arm (radius of driving wheel) = 0.17m

Forward speed of machine =100r.p.m (10.5rad/s)

Power required to overcome ground slope, P_l = 0.11kw

The power provided by petrol engine at 2,800r.p.m is 5h.p= 3.71kw See the engine characteristic power rating graph in Appendix A, figure A1 i.e. engine power rating curve.

The forward thrust ($P_s + P_r$) of the machine will be 1.11 kw and the engine will need to supply draw bar power 1.22kw plus wheel slip and rolling resistance losses giving gross total of 2.35kw.

This can be expressed further as thus:

From equation 3.3 power at ground drive $P_d = P_s + P_r + P_l + P_t = 2.35kw$

Where available engine power, $P_e = 3.71kw$

Hence from equation 3.2, $P_g = P_e - P_d = 1.36kw$

i.e. 1.36kw will be available for power losses in gear box, speed reduction box and other power transmission unit.

3.3.4 Machine stress and structural analysis

Main shaft size design for front wheels

Shaft design was done according to the method given by Greenwood (1962) and Krutz et al (1984). All from first principle of mechanics.

Combined torsion and bending were considered in the shaft design which was based on the maximum shear theory that gave reliable results so far as the strength is concerned.

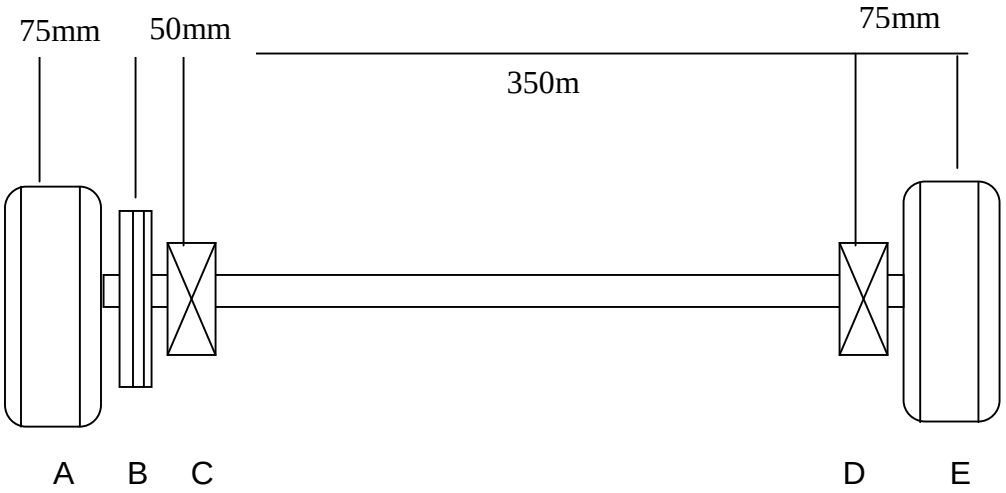


Figure 3.3: Arrangement of tyres, bearings and pulley on the front main shaft.

Torgue on the Shaft

The torsional strength of the shaft was considered by calculating the drive torque of rotating shaft which was subjected to both twisting and bending. The torque was calculated from first principle thus bearing in mind that weight on the front driven wheel was assumed 45kg for this prototype.

Torque T = 75Nm from Equation (3.4)

Where Power transmitted, P = 0.787kw

ω = 100r.p.m angular velocity = 10.5rad/s

Tangential drive load on the shaft

Tangential force on pulley drive = $\frac{\text{Torque}}{\text{Pulley radius}}$ from equation 3.4

Tangential force on pulley B, $F_B = \frac{75}{0.075} = 1{,}000N$

The pulley was 18^0 horizontally connected to pulley B which therefore, makes the F_B to have both horizontal force and vertical components on the shaft.

Bending Moment on the Shaft

The stress due to bending along the length of shaft was assumed insignificant compared to the remaining lengths at both ends of the shaft. The forces on the shaft in the Figure 3.3 are as shown below for vertical forces. This was due to the evenly distribution of weights along the shaft length which is symmetrical with greater resistance to bending due to large second moment of area along this length. The reactions of

forces on the shaft in figure 3.3 are as shown below for vertical forces.

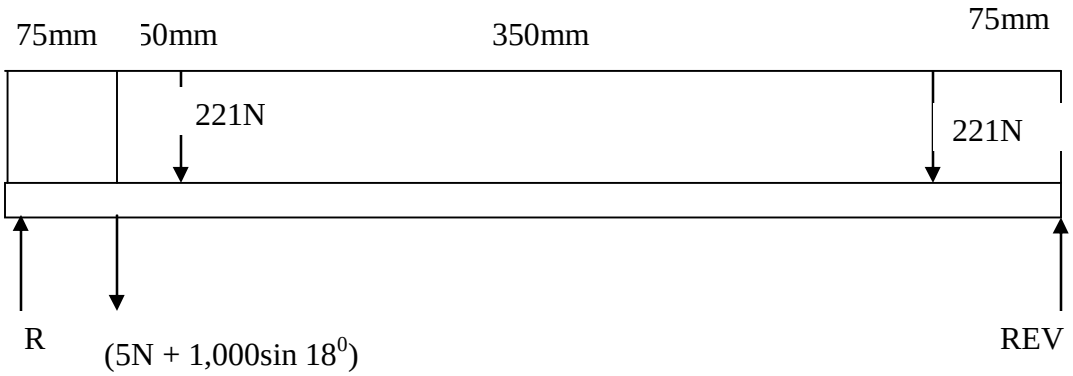


Figure 3.4 – Vertical loads acting on main shaft and their positions. The values of R_{AV} and R_{EV} for vertical forces on the tyres are:

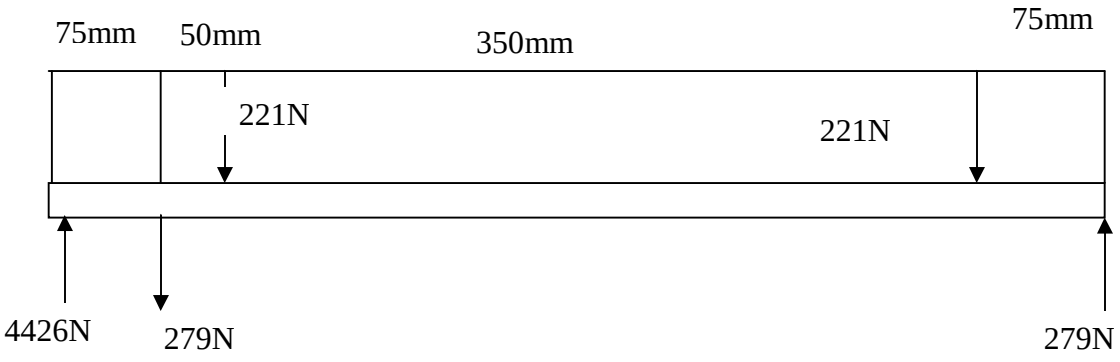
Take moment about point A ↳ +Ve

R_{EV} x 0.55 – 279 x 0.075 – 221x 0.125 – 221x 0.475 = 0,

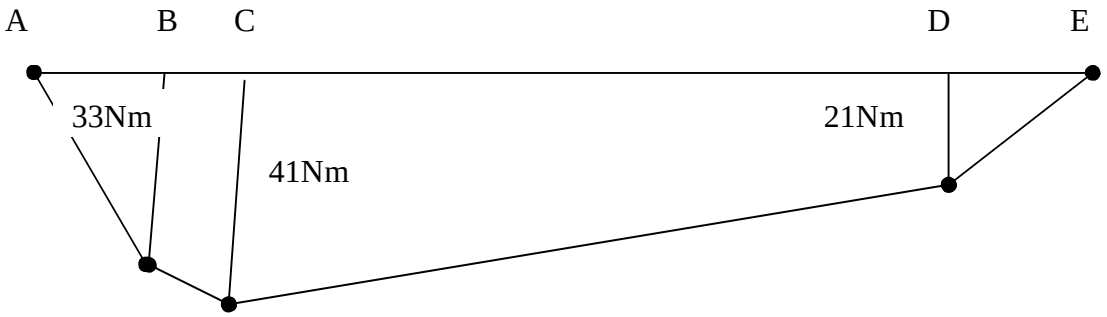
R_{EV} = 279N

Sum of vertical forces: R_{AV} + 279 = 279 +221 + 221, R_{AV} = 442N

a. Bending moment on the shaft due to vertical forces



b. Bending moment diagram of the shaft: vertical loading

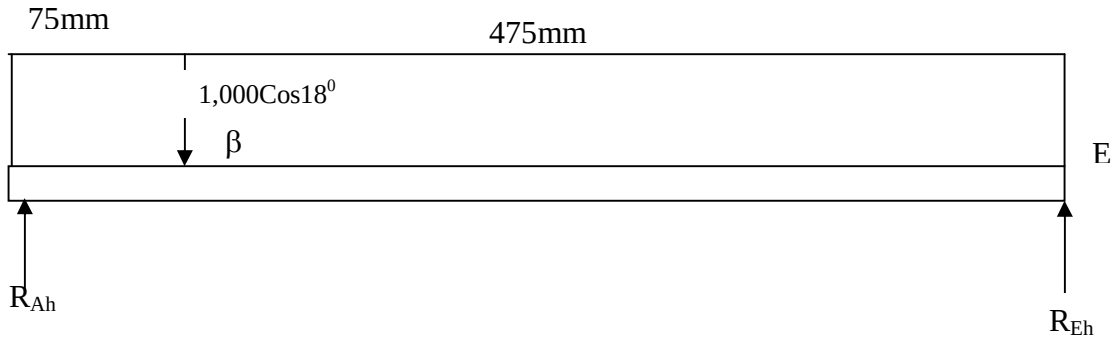


Bending moment at X = 442mm from A, 442 X 0.075 = 33Nm

Bending moment at X = 100mm from A, 442 x 0.125 – 279 x 0.05= 41Nm

Bending moment at X = 600mm from A, 442 x 0.475 – 279 x 0.4 – 221 x 0.35 = 21Nm

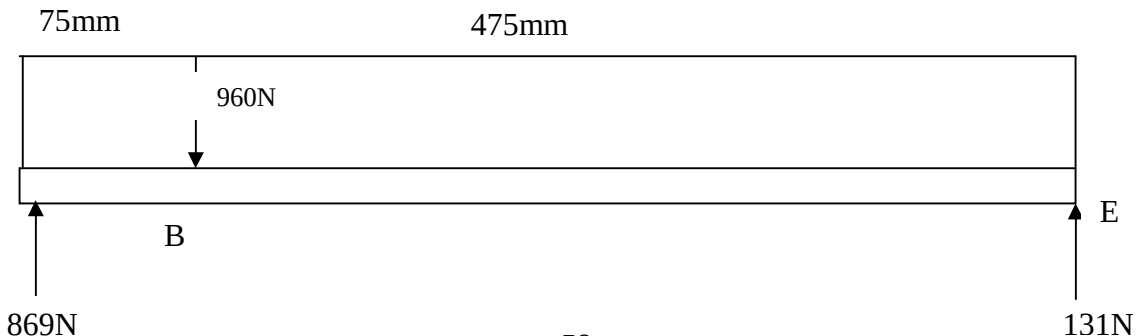
Resolving the forces horizontally



Taking moment about A ⟶ +ve, 960 x 0.075 = R_{Eh} x 0.55, R_{Eh} = 131N

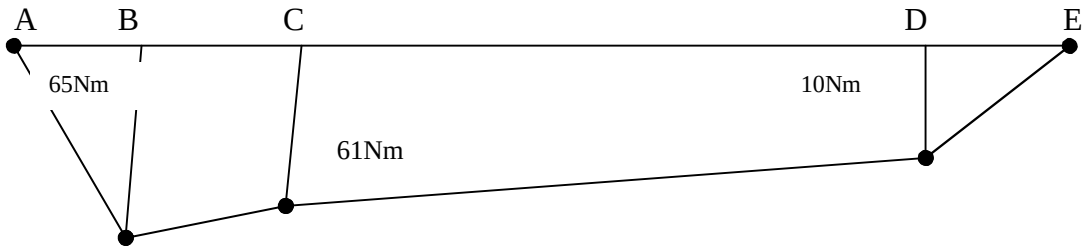
Resolving vertically, R_{Ah} = 869N

a. Bending moment on the shaft due to horizontal forces:



b. Bending moment diagram of the shaft: horizontal loading

(a) Loading (b) Bending moment



To find the total resultant component of the horizontal and vertical bending moment at B, C, D

At B, resultant component = $\sqrt{33^2 + 65^2}$ = 72Nm

At C, resultant component = $\sqrt{41^2 + 61^2}$ = 73Nm

At D, resultant component = $\sqrt{21^2 + 10^2}$ = 23Nm

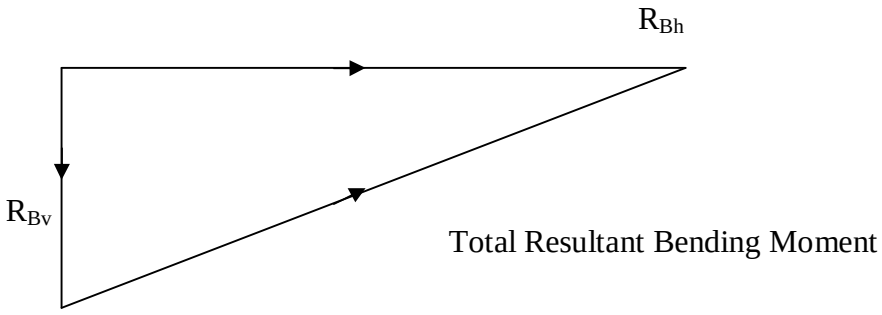


Figure 3.5: Total resultant of both vertical and horizontal bending moment on the shaft.

At C, resultant component = 73Nm

Hence the maximum bending moment on the shaft, M = 73Nm at

point B.

Calculation of Shaft diameter based on shear stress and moment

To calculate the size of shaft diameter, the maximum bending moment was selected. Because the shaft carries both bending and tension, combined stress theory was used by applying maximum static shear stress from maximum shear stress theory as follows:

The shaft diameter was calculated from the following formula with shock loading in the design of rotating shaft.

$$d^3 = \frac{16}{\pi S_S}\sqrt{\sqrt{(KmM)^2 + (K_T T)^2}} \quad \text{---------- (3.6) (Krutz et al, 1984)}$$

Where $T = \frac{\pi d^3}{16}\tau_{all}$ ..... (3.7) $M = \frac{\pi d^3}{32}\sigma_{all}$ ..... (3.8)

τ_{all} = 55.2 x 106N/M^2 allowable shear stress of shaft (Black and Adams, 1981) and (Hall et al., 1980)

Maximum bending moment of shaft, M = 73Nm

σ_{all} = allowable stress (direct, N/M^2)

d = Diameter of shaft, m

Torque on the shaft, T = 75Nm

Combined fatigue and Shock loading factors of the shaft,

K_m = 2, K_t = 1.5 see table A1

d = 24mm based on shear stress and moment

Designing shaft based on deflection

Deflection is important in the design of transmission shaft, if these shaft deflect too much, the teeth will not mesh properly and impact will be more violent, creating wear, higher stresses, and noise. Therefore low deflection is to be obtained. Once the load is determined, the cross section can be changed to minimize deflections (Krutz et al, 1984) and Benham and Warnock (1973)

Maximum deflection $y_{max} = \frac{P_c L^3}{48EI}$ ---------- (3.9)

and $I = \frac{\pi d^4}{64}$ ---------- (3.10)

Let the maximum allowed deflection be $\frac{1}{8}$ of diameter d i.e. $y_{max} = \frac{d}{8}$

i.e. $y_{max} = \frac{P_c L^3}{48EI} = \frac{d}{8}$ .....(3.11)

Where shaft diameter d is in m

Concentrated load, P_c = 1.00KN

Shaft length, L = 0.35m

Young modulus of elasticity, E = 205MN/m^2

Moment of inertia, I

Maximum shaft deflection allowed, y_{max} in m

$\therefore d = 5\sqrt{\frac{P_c L^3 X4X64}{48E\pi}}$.....(3.12) (Krutz et al, 1984)

d = 15mm based on deflection

Therefore selecting shaft diameter of 25mm is appropriate.

3.3.5 Shaft size design for stripper rotor unit

Following the same procedure in section 3.3.4, M = 6Nm and T = 2.65Nm, K_m = 2 and K_t = 1.5

Then diameter of stripper rotor unit was d = 7mm based on shear and moment. Maximum deflection of uniformly distributed load from procedure in section 3.3.4 for deflection calculation, W = 196.2N/m, d = 8mm based on deflection.

Therefore stripper shaft diameter 10mm was selected.

3.3.6 Design for rear wheel shaft size

Following the same calculation procedure in section 3.3.4 above, M = 48.4Nm, T = 58.4Nm, K_m = 2 and K_t = 1.5

Hence, d = 12mm based on shear and moment and shaft 15mm diameter was finally selected.

3.3.7 Design for first and second idler shaft sizes

The first idler shaft transmitting power from the engine (prime mover) was selected to be 25mm diameter same as front wheel shaft which is the highest power transmitting unit. While the second idler shaft was selected to be 20mm diameter since it is still transmitting part of the substantial amount of power to front wheel shaft and auger unit.

3.3.8 Auger Shaft size design based on shear and moment

From section 3.4.1, where M = 6.2 Nm and T = 5Nm

d = 6mm based on shear and moment.

Designing auger shaft based on deflection

Maximum deflection of uniformly distributed load from section 3.3.4 deflection calculation with W = 196.2 N/m, d = 9mm based on deflection. Therefore selecting auger shaft diameter of 10mm was

appropriate.

3.3.9 Auger pitch and screw diameter design

From Lower et al (1994)

$$CFTHR = \frac{(D^2 - d^2)\, P_a \times RPM}{215 \times 10^{-4}} \text{----------[3.13]}$$

Where CFTHR = Material being moved by a full auger = $1.06 m^3/h$.

The bulk density value as $839 kg/m^3$

D = diameter of screw (m)

d = diameter of shaft (m) = 0.01m

P_a = pitch of the auger (m) (usually pitch is equal to D)

RPM = revolution of the shaft = 150r.p.m

Hence D = P_a = 0.054m

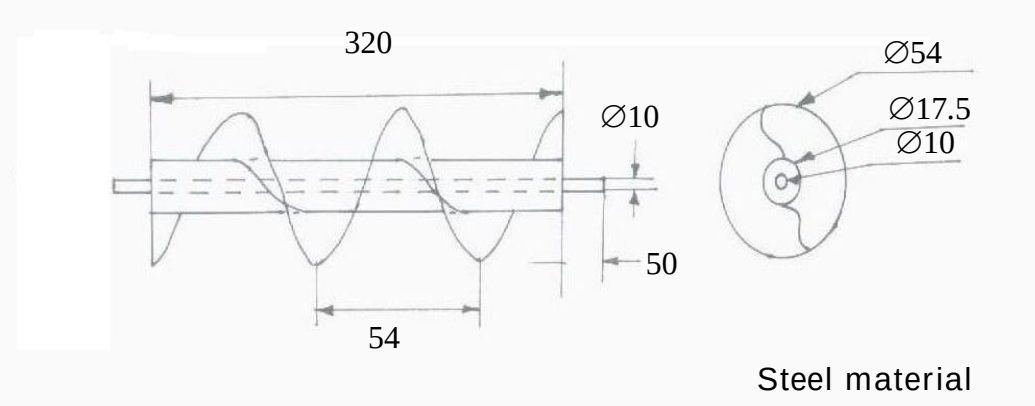


Figure 3.6 Screw Auger

3.3.10 Belts and pulleys design and selection

Below is the belt and pulleys (sheaves) arrangement of the rice stripper for power transmission. Equations from Krutz et al (1984).

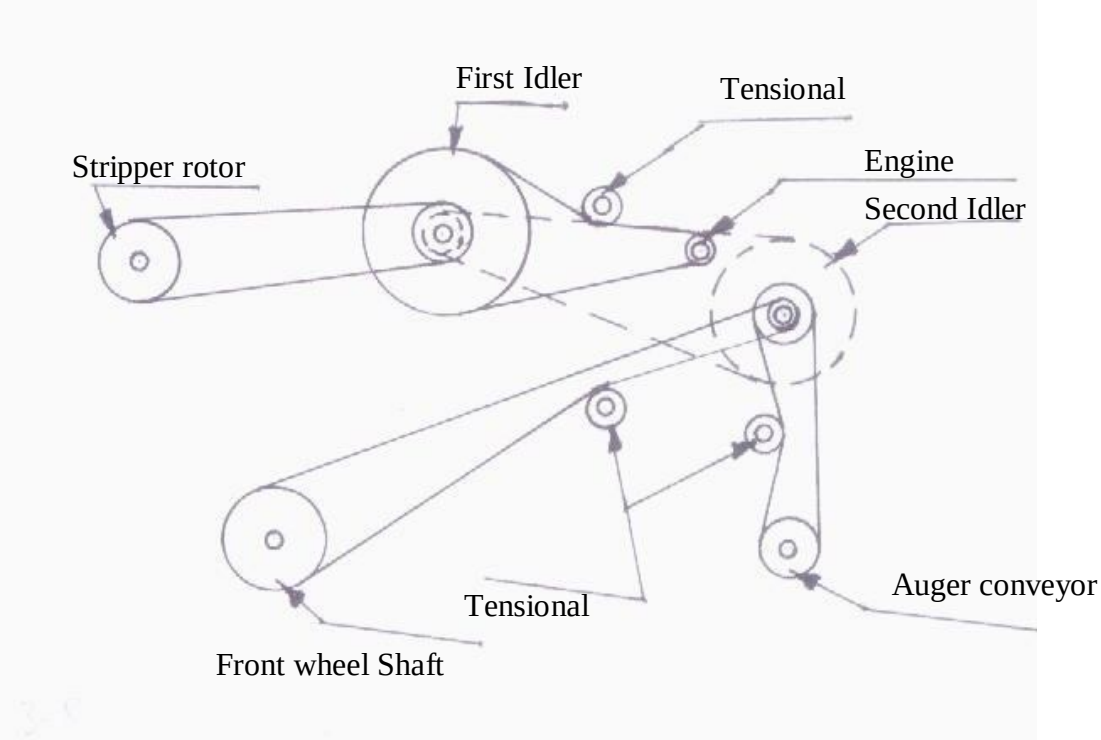


Figure 3.7 – Belts and pulleys arrangement for rice stripper

a. Speed ratio is $\frac{PD_R}{PD_N} = \frac{RPM_N}{RPM_R}$ --------(3.14) (Krutz et al, 1984)

Where PD = Pitch diameter mm

RPM = Shaft Speed, m/s or r.p.m

R = Driver pulley

N = Driven pulley

With known reduced engine speed through speed reduction box of 700rpm, and the maximum design stripper speed of 800rpm, auger of 150 rpm and machine front movement of 100 rpm. The pulleys and belts

sizes were calculated with equation 3.14 above.

b. The approximate belt length,

$$L = 2C + \pi/2\,(PD_1 + PD_2) + \frac{(PD_1 \pm PD_2)^2}{4C} \quad \text{-- (3.15) (Krutz et al, 1984)}$$

With (+) for open, (-) for crossed in the last bracket for belt

Where L = belt length, mm

C = Center to center distance of the pulleys, mm

PD_1 and PD_2 = Pitch diameters of pulley, with $PD_1 > PD_2$, mm

From table A2 and A-section belt is selected in relation to belt driving power.

(i). The stripper belt length from equation 3.15 is 1092mm and A41 (1100mm) selected.

(ii). The second idler belt length is 1154mm – A43 (1150mm) selected.

(iii). The front drive shaft belt length is 1550mm – A59 (1550mm) selected.

(iv). The auger belt length is 688mm – A26 (700mm) selected.

(v). The first idler belt length is 1,015mm – A39 (1050mm) selected.

c. The belt speed from equation $V_b = \frac{RPM \times PD}{19100}$ ---- (3.16) (Krutz et al, 1984)

Where V_b = belt speed, m/s

RPM = Shaft speed, rpm

PD = Pitch diameter of pulley, mm

i. Stripper belt speed from equation 3.16 is 2.83 m/s

ii. Front wheel belt speed is 0.7 m/s

iii. Auger belt speed is 0.73 m/s

iv. First Idler from engine speed is 8.7m/s

v. Second Idler speed is 2.1m/s

d. The effective pull from equation $(T_1 - T_2) = \frac{1000 \times P_b}{V_b}$ --------- (3.17)

Where T_1 = tight side tension, N

T_2 = Slack side tension, N

P_b = power, kw

V_b = belt velocity, m/s

i. Stripper belt effective pull from equation 3.17 is 260N

ii. Front wheel belt effective pull is 1000N

iii. Auger belt effective pull is 151N

iv. First idler from engine effective pull is 268N

v. Second idler effective pull is 105N

e. Belt speed design tension ratio (krutz et al., 1984)

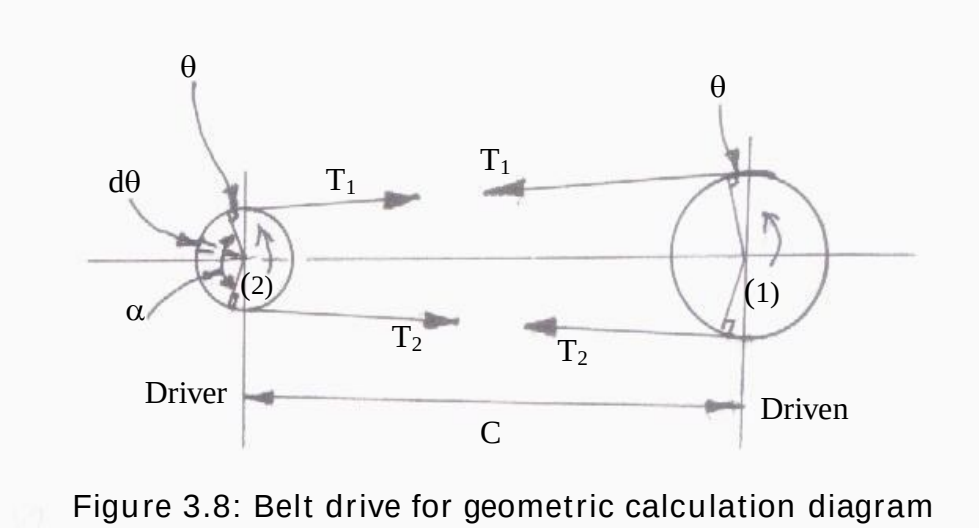


Figure 3.8: Belt drive for geometric calculation diagram

$R_A = \exp\left[\frac{0.5123\theta\pi}{180}\right]$ ..... (3.18) (Krutz et al, 1984)

Where R_A = Allowable design tension ratio

θ = Arc of contract, deg.

π = 3.14 rad.

C = Center to centre distance of pulley, mm

PD_1 = Bigger pulley diameter, mm

PD_2 = Smaller pulley diameter, mm

The arc of contact

$$\theta = \pi - \frac{PD_1 - PD_2}{C} \text{ (rad) } \ldots\ldots\ldots\ldots \text{ (3.19) (Krutz et al, 1984)}$$

Allowable (design) tension ratio R_A and belt contact angle for

(i) Stripper rotor drive is 4.7 tension ratio and belt contact angle 172^0.

(ii) Front wheel drive is 4.4 tension ratio and belt contact angle 171^0.

(iii) Auger drive is 5 tension ratio and belt contact angle 175^0.

(iv) First idler prime mover drive is 4.2 tension ratio and belt contact angle 139^0.

(v) Second idler drive is 4 tension ratio and belt contact angle 152^0.

Below are values of the angle of contact factor C_a obtained from Appendix A, table A3:

(i) For stripper, forward and auger drives 0.984 obtained.

(ii) For first idler mover drive, belt contact factor was obtained as 0.88.

(iii) For second idler drive belt contact factor was obtained as 0.924.

f. Power rating per V-belt strand is given be Reshetov (1978) as

$$P_w = \frac{P_0 C_a C_L C_M}{K} \quad \text{.....(3.20)}$$

Where P_0 is the tabular value of power per belt as shown in table A4 which in this case is 1.23Kw for the drives.

K is dynamic load and service factor from Appendix A, tables A5 and A7as 1.2

C_a is angle (arc) of contact factor shown earlier for each drive.

C_L is a factor taking the belt length into account: $C_L = \sqrt[m']{\frac{L_0}{L}}$ ... (3.21)

L = belt length, L_0 = conditional length of the belt, and m′ is power from the belt fatigue curve equation for which a value of 6 has been recommended (Reshetov, 1978). L is there for equal to:

(i) For stripper drive, $C_L = 1.001$

(ii) Front wheel drive, $C_L = 1.000$

(iii) First Idler belt drive, $C_L = 1.006$

(iv) Second Idler drive, $C_L = 0.999$

(v) Auger drive, $C_L = 1.003$

C_M is the belt material factor which is 1 for belts with polyester fibre core (Lavsan); 0.85 for polyamide (capron) fibre core and 0.7 for

high strength rayon core. The value of 1 was taken for these for all driving units.

Hence, power per belt strand;

(i) Stripper drive power from equation 3.20 was 1.01KW while 1.06Kw was transmitted to stripper. i.e the number of belt strands required was $\frac{1.06}{1.01} \approx 1$. One strand of belt was required to drive the stripper rotor unit.

(ii) Front wheel drive power was 1.01KW while 0.88KW was transmitted to move machine forward. Therefore the number of belt strand required was $\frac{0.88}{1.01} = 0.87$ i.e one strand of belt required to drive machine forward

(iii) First Idler belt drive power was 0.91Kw while 1.23KW was transmitted by this Idler. Therefore the number of belt strands required was $\frac{1.23}{0.91} = 1.35$ strands. 2 strands of belt was required to drive the first Idler.

(iv) Second Idler belt drive power was 0.95KW while 0.95KW was transmitted by this Idler. Therefore, the number of belt strand Required is $\frac{0.95}{0.95} = 1$ strand. i.e 1 strand of belt was required

(v) Auger drive power was 1.01KW while 0.05KW was transmitted by this drive. Therefore the number of belt strands required was $\frac{0.05}{1.01} = 0.05$ strand. i.e 1 strand of belt was required

g. From table A6 sheave groove angle $\beta = 30^0$ was selected for all drives belt mass from Appendix A, table A6 was selected as:

(i) Stripper belt mass = 0.098kg

(ii) Front wheel drive belt mass = 0.139kg

(iii) First Idler drive belt mass = 0.094kg

(iv) Second Idler drive belt mass = 0.103kg

(v) Auger drive belt mass = 0.063kg

h. To determine the shaft load T_1 and T_2 the net tension ($T_1 - T_2$) effective belt pull (Krutz, et al., 1984).

$T_1 - T_2 = \frac{2T}{D}$ ..... (3.22) where T = Torque acting on the driver pulley. see table A8

T_c = Centrifugal force, WV^2g

And $\frac{T_1 - T_C}{T_2 - T_c} = e^{fc\theta}$ ....(3.23) f_c = Coefficient of belt friction from table A6 = 0.5

θ = contact angle, radians.

The torque on the driving pulley was obtained from the relation

$T\omega$ = power

Section (d) above gave values for $T_1 - T_2$.

Hence

(i) For stripper drive, T_1 = 334N and T_2 = 74N

(ii) Front wheel drive, T_1 = 1,286N and T_2 = 286N

(iii) First Idler drive, T_1 = 382N and T_2 = 114N

(iv) Second Idler drive, T_1 = 144N and T_2 = 39N

(v) Auger drive, T_1 = 193N and T_2 = 42N

3.3.11 Bearing size selection

Optimum bearing performance was accomplished by appropriately selecting bearing and shaft by their load carrying capacity with their design factor determination as shown below stepwise. Below is example calculation for the front wheel shaft bearing design (Krutz, et al., 1984).

Step1 is to determine

1. Static loads supported by the bearing = shaft and pulley assembly (22.12N) and front machine weight (441.45N) on two bearings which is 232N per bearing.
2. Applied loads i.e forces applied on shaft during normal operation which is wheel tyre reaction on shaft from section 3.3.4 is 975N at A and 308N at E.
3. Drive loads i.e forces transmitted from power source to the shaft through V-belt from section 3.3.4 is 1000N

The radial load acting on the shaft, i.e power transmitted by the drive is:

$F_r = \frac{KWx19.1x10^6xk_d}{PD \times rpm}$ ..... (3.24) where F_r = radial force on the shaft, N

Kw = power transmitted, 1Kw

PD = Pulley diameter, 125mm

rpm = shaft speed, 50rpm

K_d = drive tension factor for V-belt drive

= 1.5 (Krutz et al., 1984)

Hence F_r = 4,584N

Step 2

From section 3.3.4, radial forces acting on bearings are 4011N on C and 573N on D.

Step 3

To combine forces vectorially to obtain resultant radial force acting on each bearing. (section 3.3.4) resultant force on bearing C = 4017N resultant force on bearing D = 614N

Step 4

Resultant thrust on shaft at point A is 975N and 308N at point E.

Step 5

To calculate equivalent radial force using the total resultant radial and thrust forces.

$F_e = F_r + 1.47F_t$ .....(3.25) Where F_e = equivalent radial force, N

F_r = resultant radial force, 4017& 614N

F_t = resultant thrust force, 975 & 308N

For bearing C, F_e = 5,450N

For bearing E, F_e = 1,067N

Step 6

To calculate required radial load capacity for bearings with combined radial and thrust loads, required load capacity is

$F_c = F_e \times M_s$.....(3.26) where M_s is operational or service factor from

Table A9 = 1.4

For bearing C, F_c = 7.630KN

For bearing E, F_c = 1.494KN

Step 7

To select bearing size and type from load rating with values of required load capacity above from table A10:

Bearing number 205 single row deep groove ball bearing 25mm bore was selected.

The same procedure was followed to select the bearings to carry the required radial load for the stripper assembly, first and second Idler shafts and rear wheel assembly units number 202 of 15mm bore while number 200 of 10mm bore for auger unit were selected.

3.3.12 Design for bolts and nuts

The size of bolts and nuts that holds front wheel frame to the bracket was designed using the following procedure as obtained by Krutz, et al (1984) and Hall et al (1980).

Design procedure

1. W_2 is the external load on bolt, i.e. external resultant force acting on the frame at this point (see bearing design section 3.3.11) which is 5.45KN/2 bolts and 2.73KN per bolt.
2. Assuming initial preload $W_1 \approx W_2$ to choose bolt size conservatively.
3. From table A11, conservative setting clamp load is to be equal to W_1, then bolt size M6, class 4.6, root area 20.1mm^2, torque 4.05Nm and proof load 4.52KN was chosen.

From $W_1 = \frac{5000T}{d}$ .....(3.27) where, T = tightening torque, unit (7.05Nm)

d = nominal bolt diameter, 6mm

Then W_1 = 3.38KN

4. To calculate joint stiffness, $\frac{m}{m+b}$ ..... (3.28)

$m = \frac{L}{A_{eff}\,E}$.....(3.29) Where, L = bolt length, 2cm

E = steel modulus of elasticity, 207,000Mpa

and $b = \frac{L}{AE}$.....(3.30) A_{eff} = effective joint area = (5cmx4cm- $2\pi r^2$)

A = bolt area = 0.2cm^2 $\frac{m}{m+b}$ = joint stiffness of bolt and plate

τ_y = shear-stress, Mpa

τ_{max} = maximum shear stress, Mpa
W_r = resultant bolt load, KN
π = 3.14

Hence $\frac{m}{m+b}$ = 0.02

5. To calculate resultant load on bolt, W_r:

$$W_r = W_1 + W_2\left(\frac{m}{m+b}\right) \ldots\ldots\ldots (3.31) = 3.4KN$$

6 From Appendix A, tables A12 and A13, shear τ_y is ½ of proof load for class 4.6 which is 113Mpa

$$\tau_{max} = \left[\left(\frac{W_r}{2A}\right)^2 + \left(\frac{1.6T_f}{\pi d^3}\right)^2\right]^{\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots (3.32) = 85MPa$$

Where T_f = thread torque, 4.05Nm

factor of safety Fs = $\frac{\tau_y}{\tau_{max}}$ ..... (3.33) = 1.3
(falls within 1.05 –1.33, o.k)
(Krutz et al., 1984)

7. Torque range for M6 bolt and nut = 6.7Nm – 9.4Nm

8. From above, since $W_2 < W_r$, there will be no functional point failure.

The same procedure was followed to select bolts and nuts for major force loading parts of the machine.

3.3.13 Harvester tyre selection

Traction mechanics for rubber tyre selection

The soil sample was taken from the field site and penetrometer

reading was conducted after a 24 hour period without rain at this field site. The equations and procedures for calculating and selecting rubber tyre were all taken from Liljedahl et al, (1979) for drier soil condition than fadama soil. The soil type was of loamy silt sand the soil moisture content was 11% (wet basis) for 0 – 15cm top soil.

The cone index, CI reading was 65N/cm^2 (650kN/m^2)

Refined mobility number, $Cn = \frac{CIbd}{W_l}$.... (3.34) which is wheel numeric

Wheel slip $S = 1 - \frac{Va}{V_t}$ ..... (3.35) where V_a = actual travel speed, km/h

V_t = theoretical wheel speed = $r\omega$

r = rolling radius of wheel on hard surface at no load.

ω = angular velocity of wheel

i.e $r = \frac{\text{distance travelled/wheel revolution}}{2\pi}$ ..... (3.36)

Laboratory test carried out on this prototype machine gave the load on the tyre, W_l = 0.975KN

V_a = 4.5km/h

V_t = 4.95km/h

r = 0.16m

therefore wheel slip, S = 0.1

Cn = 23.3

From Liljedahl et al., (1979), practical restriction to select rubber tyre size are, $b/d \approx 0.30$, $\delta/h \approx 0.2$ and $\frac{r}{d} \approx 0.475$

Therefore if tyre diameter d = 0.35m, tyre width b = 0.1m, tyre section height h = 0.06 where tyre deflection under load $\delta \approx 0.20h$(m) selected.

Then:

(i) Motion resistance ratio ρ = $\frac{TF}{W_l} = \frac{1.2}{Cn} + 0.04$..... (3.37)

= 0.09

Hence towed force, TF = 0.09KN

(ii) Gross coefficient of traction,

$$\mu_g = \frac{F}{W_l} = \frac{T}{rW_l} = 0.75\left(1 - e^{-0.3CnS}\right) \text{.....} (3.38)$$

$$= 0.29$$

Hence gross tractive force T = 0.059KN

(iii) Net traction coefficient, $\mu = \frac{H}{W_l} = \mu_g - \rho$.....(3.39)

$$= 0.2$$

Pull, H = 0.2KN

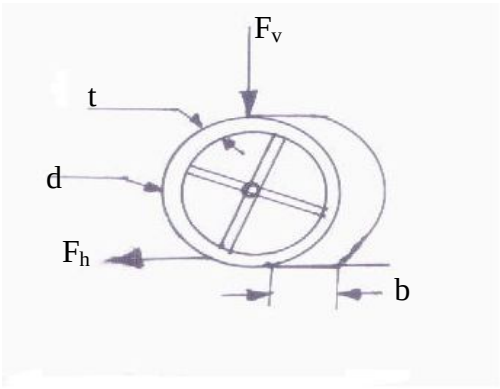
(iv) tractive efficiency, TE = $\frac{H/W_l}{F/W_l}(1 - S)$.....(3.40)

$$= 71\%$$

Therefore, selecting tyre size 0.35m diameter, 0.1m width, 0.06m section height with pressure 1.8kgf/cm^2 (26P.S.I) gave 71% tractive efficiency for the loamy silt sand soil at 11% moisture content (wet basis).

3.3.14 Metal tyre traction design

The following procedure was used in designing a nondeformable tyre on deformable surface (metal tyre) to improve on machine traction in wetter soil condition where rubber tyre may not perform well.



Where, F_v = vertical force on tyre, N
F_h = horizontal force on tyre, N
R_t = resultant force on tyre, N
A = Tyre contact area with soil, m^2
P_p = resisting resultant pressure on tyre, N/m^2
b = width of tyre, m

Figure 3.9 Forces, and reactions on metal tyre in motion.

Where t = wheel tyre thickness, m
P_p= pressure on the wheel, N/m^2
d = diameter of the wheel, 0.34m
S_s = allowable shear stress of metal plate, $55x10^6 N/m^2$
(Jensen & Chenoweth, 1975)

To obtain minimum required wheel (tyre) thickness of a cylinder, there is a resisting pressure, P_p

Required wheel thickness of cylinder (tyre), $t = \frac{P_p d}{2S_s}$ .....(3.41)

(Jensen & Chenoweth, 1975) and (Benham & Warnock, 1975).

Maximum resultant force on front tyre is 975N (section 3.3.4)

The width of tyre is, b = 0.08m and contact length on soil ℓ = 0.1m, where contact area, $A = 0.78b\ell$ (m^2)..... (3.42) (Liljedahl, et al., 1979).

Hence wheel thickness, t is 0.7mm. To design for worst soil conditions,

tyre width 0.08m was chosen and the tyre metal steel thickness, t value of 2mm chosen to construct steel wheels with V-lug design on the surface at 0.08m spacing.

3.3.15 Grain stripping operation power determination

The stripper rotor simultaneously carries out four functions: crop lifting; harvesting; partial threshing's and crop transportation that corresponds to the functions of the crop reel, cutterbar, threshing drum and crop conveyor on a conventional combine harvester, Douthwaite *et al* (1993).

Grain detachment force depends on the crop stalk and grain moisture content, thickness of the stalk at point of detachment, maturity stage of crop, condition of detaching mechanism and other factors. The power required for grain stripping operation can be summed up as:

- Power to carry and rotate stripping unit, P_1 (kw)
- Power for rotor unit to overcome air (wind) resistance, P_2 (Kw)
- Power to strip grains and M0G from stalk head, P_3 (kw).

From the first principle of mechanics as in Greenwood (1962), Krutz et al (1984) and Ojha and Michael (2003).

$P_1 = \frac{m_s g r \omega}{1{,}000}$ (w) .....(3.43) where, m_s = Mass of stripping unit, (6kg)

$= 773w$ g = acceleration due to gravity, $9.8/m/s^2$

r = radius of the stripper rotor, 0.25m

ω = angular velocity, 52.5rad/s.

$P_2 = 0.01099AV_w^3$ (w)..... (3.44)

where A = perpendicular area to wind direction, m^2

$= 0.212cm^2$

V_w = wind velocity, m/s (2.34m/s)

P_2 = power of wind resistance, = 0.03w (negligible).

The sum of P_1 + P_2 (773.03w) will be the power consumed by the stripping header at no stripping (at no load). The power of the stripping header measured when stripping grains and MOG minus when not stripping gave the actual power to strip grains and MOG alone (P_3).

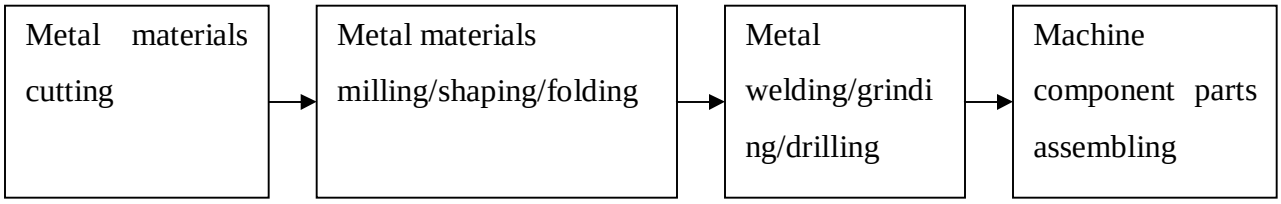
3.4 Fabrication and Assembly

The machine components selection and fabrication was carried out to ensure adequate strength, reliability and durability and overall low cost production. The machine parts that strips and handles grains were made of selected abrasion resistant material, tyre rubber linning of 300mm by 60mm. The front wheel shaft was made of 350 mm long x 25 mm diameter mild steel machined to size. The mainframe was made of two 800mm x 50mm x 5mm flat bar mild steel electrically welded to designed shape. The body cover was made of 1.8mm sheet metal welded with gas to form the body cover. The power transmitting unit was made of belts and pulleys of various sizes; while the crop conveying and handling unit was made of 320mm length and 54mm pitch and diameter auger conveyor. The power source was from a 3.71kw petrol engine. Also incorporated for the self propelled machine was steering unit made of a 25mm diameter and 700mm length galvanized T pipe connected to the third, articulated tyre assembly behind the machine. Clutch unit was

made of idler pulley and belt tension type and traction unit was of three x 350mm diameter tyres.

Machine component parts were fabricated by cutting, shaping, milling, folding/bending and welding according to the designed technical drawing shapes, sizes and tolerances in the Department of Agricultural Engineering workshop, ABU, Zaria, with Lathe, Milling, Cutting, Drilling, Folding, Electrical and Gas Welding Machines.

Machine Production Process Layout



CHAPTER FOUR

4. EVALUATION OF THE MACHINE

4.1 Experimental Procedure

The sections below describes how the field experimental procedure and rice physical properties determination were carried out.

4.1.1 Crop material

The machine was designed to harvest rice whether planted in rows or broadcast or spot planted. The rice field where this machine performance testing was carried out was spot planted on level ground of loamy silt sand soil (rainfed upland rice) with plant to plant spacing of 25cm average as described in section 4.1.2 and crop height at maturity ranging from 55cm to 90cm. The rice variety used for the experiment was faro 44 which is one of the NERICA (New Rice for Africa) with local name Kwadala planted at Basawa area of Samaru, Zaria. The rice seed material was certified by the National Agricultural Seed Council, Samaru station, Zaria.

4.1.2 Machine Design Related Physical Properties/Characteristics of Rice Crop

The crop material (Faro 44, a NERICA variety locally called Kwadala in Zaria) on which the fabricated machine was tested, the following experiments were carried to determine its machine design related physical properties.

Rice plant population per unit area and the main stem of a rice

plant can produce up to 50 or more tillers that develop into productive tillers which both determine the yield (Mastsuo and Hoshikawa, 1993).

The following physical properties measurement of rice crop was carried out:

i. The plant to plant spacing was carried out by measuring at random all over the rice field with measuring tape distance between plant to plant up to 50 readings and average value was obtained on the spot planted rice field.

ii. The crop heights at maturity stage were measured at random all over the field ranging from short ones to the tall ones about 20 readings each and the averages were found.

iii. With $0.1m^2$ quadrat, the pre harvest loss was determined before the harvester was brought in to the field to determine losses.

iv. The average crop yield was determined by manual harvesting a $1m^2$ rice field at random taking 10 readings and found the average crop yield.

v. The angle of repose for the grain was determined by putting some grain on flat metal sheet, type of what was used for the grain box and then tilted till the grains began to flow down the slope and the angle of tilt was measured with a protractor. This was repeated 10 times and average found to determine the slope angle of grain box bottom slope, Stout and Cheze (1999).

vi. The soil moisture content and soil type were determined by bringing the soil sample of rice field into the laboratory to determine soil moisture content by oven dry method. The sample was weighed with the can and the readings of the empty and the can with the wet sample were noted. Then after 24 hours when the weight was confirmed constant the dry weight was taken to determine the dry content weight of the soil sample. The soil sample type was determined by hand feeling and physical observation.

$$M_c\ (w.b)\% = \frac{W_w - W_d}{W_w} \times 100 \quad \text{.....(3a)}$$

Ndirika and Oyeleke (2006)

Where M_c(w.b) = moisture content on wet basis

W_w = weight of wet sample (g)

W_d = Weight of dried sample (g)

vii. The grain dimensions were measured with a vernier caliper (fisher scientific company, Pittsburgh, Pa) having a least resolution count of 0.01cm was used. The geometric mean diameter, Dg of the grain was calculated using the following relationship as described by Mohsenin (1986).

$$Dg = (LBT)^{1/3} \quad \text{..... (3b)}$$

Where L, B and T are the grain length, width and thickness samples of 50 randomly selected kernels of rice were used to determine the average or mean dimensions.

viii. The volume of the grain was determined by taking the dimensions of the grains selected in three areas of length, width and thickness, and then the volume was estimated using the following relationship as described by Mohsenin (1970).

$$V = \frac{\pi Lwh}{6} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3c)$$

Where V = volume of kernel

L = Length of kernel

W = Width of kernel

h = thickness of kernel

ix. The bulk density of the rice grain was obtained by measuring the weight of the selected grains. Having determined its volume then from the following the bulk density was determined to design auger conveyor capacity.

$$\text{Bulk density} = \frac{\text{weight of material packed}}{\text{Known volume}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3d)$$

(Ndirika and Oyeleke, 2006)

x. The grain moisture content was determined as shown in (vi) above of grains randomly taken from field. This was monitored until the right harvesting crop moisture content was obtained for the matured crop. To determine appropriate harvesting grain moisture content.

xi. The average ground slope was determined by an Abney level instrument for the harvester machine maximum slope effect determination. This was done by setting the Abney level to take

angle of inclination on two pegs set apart and measured horizontal distance. With this, the vertical difference in height over the horizontal distance gave the ground slope value. This was repeated several times and average readings taken and maximum also was determined.

xii. The rice straw, leaf and rice paddy grain abrasiveness was established to determine the type of material for stripping and handling the stripped grains and MOG.

xiii. The average number of tillers per hills was determined by counting the tillers on hills which was conducted at random all over the field on 20 hill samples. Also average straw thickness beneath the grain head was measured at random with vernier caliper for about 50 samples. This was to determine stripping element keyhole diameter (product of number of tillers by average straw thickness).



Plate 4.1: Dynamometer Mounted on the Machine to measure Power



Plate4.2: Soil Investigation taking place in the rice field

4.1.3 Preliminary field experiment

A pre-field or preliminary field experiment was carried out to study the performance of the machine at various settings of the functional component machine parts to identify which part require modification. All the necessary adjustment and modifications has been done. The preliminary field experiment on rice field can not be carried out elaborately until there was ripe rice field before the real field data was taken. The field experiments were carried out on an upland rice field along Basawa road, Samaru, in mid September, 2008.

4.1.4 Laboratory tests

The laboratory tests were conducted to determine the forward speeds, rotor speeds and conveyor speed with digital tachometer. The power requirement by the stripper at each setting was taken by dynamometer and time taken with stop watch while length was measured with measuring tape. The power of the prime mover petrol engine was measured and the speed too. The actual ground speeds of the harvester was obtained by running the machine through a marked distance and timed (Plate 4.1).

4.1.5 Measurement of power required to detach rice grains

Attempt was made to measure directly the power required to release rice grains from the ear during stripping operation by a dynamometer on the field using the formula below:

$$\text{Stripper rotor power} = \frac{2\pi nT(w)}{60{,}000} \quad \ldots\ldots\ldots (4.1)$$ Liljedahl, 1983)

where, n = rotor shaft speed, rpm

T = rotor shaft torque, Nm

From the data collected by running the machine at no load (i.e not stripping) n = 500rpm, force = 106N. Force arm = 0.14m as shown in plate 4.2 of prony brakepad dynamometer, stripper rotor power = 777w. A more accurate and suitable instrument is required to measure power when the machine is both stationary and also in motion that is, when stripping. Although, Metianu et al, (1991) recorded 4.5kw/m stripping power requirement however, the only instrument available to this researcher could only measure the machine power in stationary position which was unable to determine the stripping power requirement of the 0.3m width header.

4.1.6 Field plot preparation

The crop variety fields were divided into 260 experimental plots divided into three blocks required for the field test. Each of these blocks was divided into 55 plots to test the machine and 5 plots to carryout manual harvesting. The width of each plot was 0.3m and the length was 10m. About 15 additional plots were included with four per block for trial run before the real data taking started. The total size of field required for the two crop field was 20m by 50m (0.1ha).

Randomised complete block design (RCB) as described by Gomez and Gomez (1984) was adopted to carryout the study of the effect of rotor height, forward speed and rotor speed, on header loss, MOG/grain ratio

and percentage grain threshed. That is, three variables were measured throughout each run.

- Header loss (grain lost on the stubble, logded and shatter).
- MOG/grain ratio of the material collected.
- Percentage of grain threshed in the material collected.

Header loss was measured by weighing the grain that was collected in the quadrat of known area ($0.1m^2$) made of four sided iron placed between the plants harvested and extrapolated to give the loss in kilograms per hectare. In this way pre-harvest losses was eliminated. The amount of grain left unstripped by the rotor was consistently found.

4.3 Experimental Design

4.2.1 Factorial combinations

When responses to the factor of interest were expected to differ under different levels of other factors, factorial experiment is appropriate to handle two or more variable factors (Gomez and Gomez, 1984). The effect of combinations of rotor height, forward speed and rotor speed on field performance of the rice stripping harvester and the best performance combination were determined.

A randomized complete block design (RCB) described by Gomez and Gomez (1984) was adopted to study the various levels of rotor speeds (5 levels), harvester forward speeds (5 levels), nose heights (1 level), rotor heights (2 levels) on field losses, field capacity and field efficiency. The randomization of the treatment combinations for each replication was

effected using the table of randomized numbers presented by the Gomez and Gomez (1984).

The 2 x 5 x 5 factorial treatment combinations of two levels of rotor height(R), five levels of forward speed (U), and five levels of rotor speed (V) are presented in Appendix D1.

A 2x5x5 factorial treatment combination was assigned completely at random using table of randomized numbers presented in Gupta (2005) to the 50 experimental plots in each of the three blocks. Appendix D2 shows the layout of the 2x5x5 factorial experiment involving, two levels rotor height (R_1,R_2), five levels of forward speed (U_1,U_2, U_3,U_4,U_5,) and five levels of rotor speed (V_1,V_2,V_3,V_4,V_5) in a randomized complete block design with three replications.

A three factorial experiment with a crop type was used. Two rotor heights (R) 270mm and 220mm (the height of the lowest part of the rotor above the ground), five Forward speeds (U) 3km/h, 4km/h, 5km/h, 6km/h and 7km/h and five rotor speeds (V) of 400rpm, 500rpm, 600rpm, 700rpm and 800rpm. The nose height of 100mm below plant height with hood clearance fixed. A parameter was varied while others were fixed at a time. These three factorial experiments gave 150 combinations (RxUxV) with three replications.

The time spent, field capacity, field efficiency and a total loss for machine harvesting was compared with manual harvesting. The manual harvesting was considered as a control. The rice in each of these control

plots were harvested manually. The time taken to harvest, the losses and field capacity of the manual harvesting were recorded.

4.3 Laboratory/Field Experiments

Four field men were involved in carrying out the field experiments which includes harvester operator that guides harvester through each run, the time keeper took note and recorded time taken for each run and measured amount of fuel consumed per run from a calibrated cylinder. The man that picks the unstripped grains left on the stubble (standing crop), grain left on lodged crop, grain that fell within the 0.1m^2 quadrat. A technician assisted the team to change the pulleys and belts to obtain right speeds and heights variation. The speed combinations were checked to confirm the accuracy before each run for the forward speed, rotor speed and auger speed. Also rotor height was confirmed before each run commences. The instruments made used for the laboratory and field experiment data measurements as described in section 4.1.2 and this section are as follows:

A LUTRON digital photo/contact tachometer of 0.5 to 100,000rpm range and accuracy ± 0.05% was used to measure speeds. The weighing were done in the laboratory with the Mettler Model 2010 electronic scale of up to 0.1g accuracy. An analogue stop watch which gave time readings of 0.01 seconds was used to measure time. Measuring tape of 50m length caliberated in mm was used to measure length and distance. The

grain physical dimensions were measured with a vernier caliper (fisher scientific company, Pittsburgh) with least resolution count of 0.01cm. Protactor and ruler were made use to measure angles and length respectively. The oven used for moisture content determination was an electronically controlled Eijelkamp UM-300Model MEMMERT Oven.

4.3.1 Measured parameters

The following parameters were measured for the purpose of data collection:

- The crop yield
- Pre harvest loss
- Crop moisture content at harvest
- Height of the crops
- Weight of grains left unstripped on standing crops (stubble)
- Weight of grains left unstripped on lodged crops
- Weight of materials other than grains (MOG)
- Weight of total grains and other materials stripped
- Weight of grains lost found in quadrat
- Wind velocity at time of harvest
- Time taken to reap plot
- Weight of grains threshed during harvest

Three samples of the whole crop were selected randomly from each plot immediately after harvesting for moisture content determination. The moisture content of whole rice crop, at which stripping occurred was

determined in accordance with ASAE standard S.352 (ASAE Year Book, 1979). About 500g sample of the crop was kept in an oven at 105^{o}C for 24 hours. The loss in weight of the sample was recorded and the moisture content was determined as follows:

$$MC_{wet\ basis} = \frac{W_{initial} - W_{final}}{W_{initial}} \times 100 \quad \ldots\ldots\ldots\ldots \quad (4.2)$$

The weight of the measured parameters were measured by weighing scale, length measured by measuring tape, time taken by stopwatch, fuel consumption by calibrated cylinder, speed by digital tachometer and power by dynamometer. See plate 4.3 for the rice field mark out and plate 4.4 for the rice harvester in operation. Plates 4.5 and 4.6 shows pictures of major machine components. Plates 4.7 and 4.8 shows a block of rice field before and after harvesting respectively.



Plate 4.3: Field Plots been marked out



Plate 4.4: Harvester in Field Operation

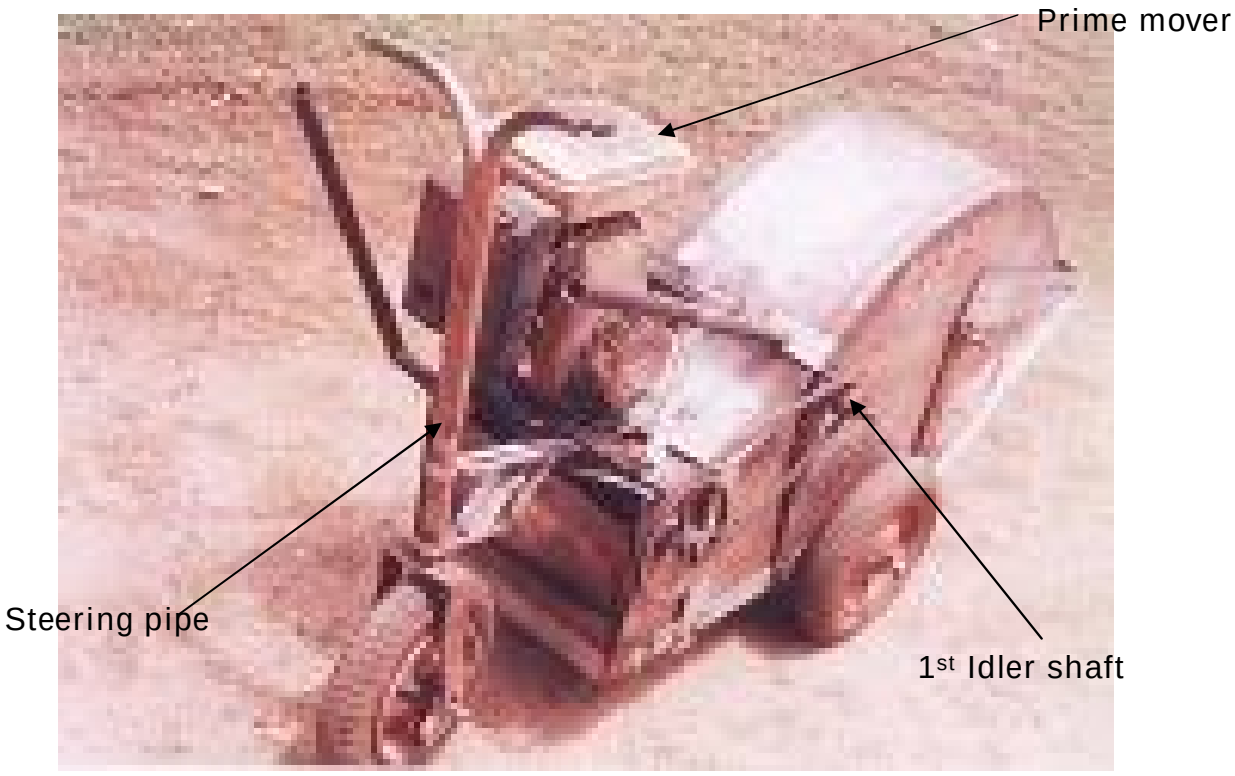


Plate 4.5: Rice Stripper



Plate 4.6: Rice stripper header



Plate 4.7: Rice field before harvesting



Plate 4.8: A block after harvesting

4.3.2 Parameters computed

The following are the parameters computed in this study:

- Shattering losses, Sl (loss caused by the header due to vibration and it impact on the crop during harvesting, kg)
- Cracked grain losses, Sc (cracked grains during harvesting, kg)
- Lodging losses, Lg (grains left behind on lodged plants, kg)
- Stubble losses, St (grains left on stubbles by the header, Kg)

Each of the losses were expressed as percentage of the total yield (TY) in each plot (Ichikawa, 1981).

$$TY = C_t + S_l + S_c + L_g + S_t \text{ (kg)} \quad \text{.....(4.3)}$$

C_t = mass of total grain and MOG harvested (kg)

$$S_l = \frac{\text{mass of shattered grains}}{TY} \times 100(\%) \quad \text{.....(4.4)}$$

$$S_c = \frac{\text{mass of cracked grains(mechanical damage)}}{TY} \times 100(\%) \text{... (4.5)}$$

$$L_g = \frac{\text{mass of grains left on lodged crops}}{TY} \times 100(\%) \text{ ..... (4.6)}$$

$$S_t = \frac{\text{mass of grains left on stubble (standing crop)}}{TY} \times 100(\%) \text{ ... (4.7)}$$

$$\text{Crop purity} = \frac{\text{mass of grain harvested}}{\text{mass of grain plus MOG harvested}} \times 100\% \text{..... (4.8)}$$

$$\text{Total crop losses } T_{tl} = \frac{S_L + S_c + L_g + S_t}{TY} \times 100\ (\%) \quad \text{.....(4.9)}$$

Fuel consumption rate =

$$\frac{\text{fuel consumed per plot (litres)} \times 10^4 (\text{litres/ha})}{\text{plot area } (m^2)} \text{ ...(4.10)}$$

Effective field capacity was determined by measuring all the time elements involved while harvesting. The whole time (total) was categorized into productive and non productive time. Productive time is the actual time used for harvesting the grains while non productive time was made up of turning time, repair and adjustment time and other time losses during harvesting as Kalsirisilp and Singh (2001) shows below:

Effective harvester field capacity = $\frac{\text{Area harvested (ha/h)}}{\text{Total time taken}}$ ..... (4.11)

Harvester field efficiency = $\frac{\text{Productive time}}{\text{Total time taken}}$ x 100(%) .....(4.12)

The harvester efficiency was calculated by expressing the mass of grain harvested (stripped) and conveyed through the box to the total yield as shown below.

$$\eta = \frac{C_{tg}}{TY} x100(\%) \quad \text{..... (4.13) (Kalsirisilp and Singh, 2001)}$$

where C_{tg} = total grain stripped and collected, kg

The grain purity was calculated as below:

Grain purity = $\frac{\text{Clean grain}}{\text{Total material stripped}}$ x 100% ...(4.14) (Kalsirisilp and Singh, 2001)

4.4 Data Analysis

The data collected from the experiments were analysed using Analysis of variance (ANOVA) technique given by Box et al (1978) and Gomez and Gomez (1984). Determination of contributing factors like forward speed, rotor speed, and rotor height influencing the parameters

like machine harvesting field efficiency, grain loss and harvesting field capacity was considered using multiple regression and student T test to compare the two harvesting methods i.e. stripping and manual harvesting methods as described by Quenonille (1950) and Gomez and Gomez (1984).

The performance of the stripper rotor was evaluated mainly on grain loss and straw intake: using Duncan Multiple Range Test (DMRT) to determine critical factors affecting the harvester performance. Consistency of the developed stripper performance operation with established experiment results from existing manual harvesting operation was statistically and graphically determined. The stripper and manual harvesting test results were graphically plotted for grain loss against stripper height, stripper speed, and rotor speed. Also MOG/grain ratio against relative stripper height and stripper speed. The line of best fit (1:1 line) and coefficient of determinant (R^2) were used to determine how well the regression equation fits the field capacity data collected.

Coefficient of determination (R^2) for the stripper prototype was determined for non-linear and linear function with one or more independent variables as Gupta (2002):

$$R^2 = 1 - \frac{V_e}{V_t} \quad \text{..... (4.15)}$$

Where, R^2 = Coefficient of determination

V_e = Estimated variance

V_t = Estimated Variance about the mean

The significance level for a given R^2 was obtained by computing 't' with the following equation

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{\sqrt{\frac{\left[\Sigma x_1^{\,2} - \frac{(\Sigma x_1)^2}{N_1} + \Sigma x_2^{\,2} - \frac{(\Sigma x_2)^2}{N_2}\right]\left(\frac{1}{N_1} + \frac{1}{N_2}\right)}{(N_1 + N_2 - 2)}}}$$ ----(4.16) Akinboye and Akinboye (1998)

Where t = student 't' value

X_1 and X_2 are the value of parameters.

$\bar{x}_1$ *and* $\bar{x}_2$ are the mean value of the parameters

N_1 and N_2 are the sizes of the 1st and 2nd groups respectively

4.5 Economic Analysis

Crop production field operations are mostly seasonal in nature with short period of available time to perform the task. Also because of this, field machinery usage is low per annual. This then call for proper economic analysis for the stripper rice harvester to determine its economic viability. The following procedure was adopted to determine the annual cost usage of the machine and compared with the cost of manual harvesting (Ajiboye, 2007).

4.5.1 Cost of machine use

Cost factors for field machine operation are charged for machine, power utilized and labour. Machine costs are categorized into fixed and variable (operating) costs. Operating or variable costs are directly related to the amount of usage which include repairs, maintenance, fuel and lubricants, and servicing (Kepner et al., 1987).

Depreciation is the reduction in value of a machine with time. Field machines are operated for only few hours per year, obsolescence is the most important factor affecting depreciation. Kepner et al., (1987) recommended straight-line method for depreciation calculation for practical purpose, and gave 10 years harvester life for obsolescence and 2000 hours or 200 hours/year wear-out life. Depreciation cost per hectare was computed as follow [residual (book) value of 10% of original cost assumed]:

$$DP_{ha} = \frac{HC - RV}{200 \times n_s \times EFC} = \frac{0.9x\ HC}{200 \times n_s \times EFC} (₦/ha) \ldots\ldots (4.17)$$

Where HC = harvester cost, ₦

RV = residual (book) value of harvester at wear-out, ₦

n_s = service life, years

EFC = effective field capacity of the harvester, ha/year

Legitimate cost of farm machinery is interest on investment. By using a straight-line depreciation, Kepner, et al., (1987) recommend that the interest charge should be constant. The prevailing interest rate is around 3% on savings.

The total interest chargeable per year (I ₦) was given as:

$$I = \frac{HC\ [(1 + i_r)^{ns} - HC]}{n_s} (₦) \ldots\ldots (4.18)$$

Where i_r = interest rate/year

n_s = number of year until obsolete or wear-out life

Total interest chargeable per hectare was estimated as follows:

$$I_{ha} = \frac{HC}{200 \times n_s \times EFC}[(1 + i_r)^{ns} - 1] (₦) \ldots\ldots\ldots (4.19)$$

Considering taxes, insurance and shelter, there is a total annual charge equal to 2% of the new cost, recommended for straight-line depreciation by Kepner et al (1987). The cost was therefore estimated per hectare as:

$$TIS_{ha} = \frac{2 \times HC}{100 \times 200 \times EFC} \quad (₦) \ldots\ldots\ldots (4.20)$$

The repair cost includes maintenance (adjusting for wear, daily service and lubrication, etc) as well as the cost of all parts and the labour to install the parts. Repair cost per hour of usage increase with age but tend to level up as the machine becomes older. A uniform annual charge for repair and maintenance in conjunction with straight-line depreciation is recommended by Kepner et al (1987) and gave an estimate of average repair cost per hour of use as 0.025% of the new cost. Repair and maintenance cost per hectare was estimated as follows:

$$RMC_{ha} = \frac{0.025 \times HC}{100 \times EFC} \quad (₦) \ldots\ldots\ldots (4.21)$$

Where, RMC_{ha} = repair and maintenance cost per hectare.

Another important cost item considered was fuel requirement per hectare, FC_{ha} which was obtained from data computed from the performance evaluation on the pedestrian controlled self propel harvester. The fuel consumption rate was converted to Naira per hectare at the prevailing market price.

Labour cost for operating the harvester was fixed based on what was paid for daily paid workers in the Institute of Agriculture Research, Ahmadu Bello University, Zaria. Labour cost per hectare was calculated

as follows:

$$LC_{ha} = \frac{DP}{8 \times EFC} \text{ (₦/ha)} \ldots\ldots \quad (4.22)$$

Where DP = labour cost/day of 8 hours

The total cost of machine usage, TC_{ha}, is the sum of all the costs enumerated above:

$$TC_{ha} = DC_{ha} + I_{ha} + TIS_{ha} + RMC_{ha} + FC_{ha} + LC_{ha} \ldots\ldots\ldots \quad (4.23)$$

4.5.2 Cost of harvesting manually

Ahmadu Bello University Institute for Agricultural Research (IAR), Zaria and International Institute for Tropical Agriculture (IITA), Ahmadu Bello University, Zaria stations had fixed daily paid farm hands employed for manual rice harvesting. This figure was made used to estimate the cost of manual rice harvesting operation.

CHAPTER FIVE

5 RESULTS AND DISCUSSION

5.1 Results

The results of the physical properties, pulleys pitch diameters determination, harvester's settings, measured field performance indices, computed field performance indices, analysis of variance, Duncan multiple range test, mechanical and manual comparison and stripper optimum settings of the machine are presented in Tables 5.1, 5.2, 5., 5.3, 5.4, 5.5, 5.6, 5.7, 5.8 and 5.9 respectively. Also the graphs of the effects of forward and rotor speeds on shattering loss, effects of rotor and forward speeds on stubble loss, effect of rotor and forward speeds on lodging loss, effects of rotor and forward speeds on total loss, contributions of various sources of loss on total loss, effects of rotor speed on time taken, effects of rotor speed on fuel consumed, effects of rotor speed on grain purity, effects of rotor and forward speeds on harvester efficiency and effects of rotor speed on field efficiency are presented in Figures 5.1, 5.2, 5., 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10 and 5.11 respectively.

Table 5.1: Machine Design Crop Related Physical Properties Measured

Physical properties	Number of samples measured	Average values	SD[a]
Plant to plant spacing, cm	50	25	4.24
Crop height at maturity, cm	20	72.5	8.94
Pre harvest loss, kg/ha	10	40	3.79
Crop yield, kg/ha	10	1,300	15.81
Angle of repose of paddy rice, degrees	10	25	0.70
Soil moisture content, percent	5	11	0.67
Geometric mean diameter grain, mm	50	4.14	0.28
Volume of grain, m^3	50	$0.36x10^{-7}$	0.15
Bulk density of paddy rice, kg/m^3	10	839	9.49
Grains moisture content at harvest, percent	10	18.3	2.85
Maximum ground slope, degrees	10	3 (5.2%)	0.25
Number of tillers per hill, number	20	10	2.13
Diameter of straw below panicle, mm	50	1.2	0.06

(a) SD= Standard deviation

TABLE 5.2: Pitch diameters of pulleys

Parameters	Pitch diameter of pulley on prime mover (mm)	Pitch diameter of pulley on Idler 1 (mm)
	50	238
	Stripper rotor pulleys	
Rotor speed, V rev/min	pitch diameter of pulley on Idler 1 (mm)	Pitch diameter of pulley on stripper shaft (mm)
400	73	110
500	73	90
600	73	70
700	73	60
800	73	50
	Idler 1 and Idler 2 pulleys	
	Pitch diameter of pulley on Idler 1 (mm)	Pitch diameter of pulley on Idler 2 (mm)
	50	220
	Forward drive pulleys	
Forward speed, U (k m/h)	Pitch diameter of pulley on Idler 2 (mm)	Pitch diameter of pulley on front wheel shaft (mm)
3	45	150
4	45	140
5	45	125
6	45	100
7	45	85
	Auger drive pulleys	
	Pitch diameter of pulley on Idler 2 (mm)	Pitch diameter of pulley on Auger shaft (mm)
	80	75

Where: V is the stripper rotor speed (revolution/minute)

U is the stripper harvester forward speed (km/h)

Table 5.3: Values for the Harvester's Settings

Level	Rotor height above ground, mm		Forward speed, km/h			Stripper rotor speed, rpm		
	Design	Actual	Design	Free motion	Forward motion	Design	Free motion	Forward motion
1	300	270	3	3.2	2.75	400	410	400
2	200	220	4	4.3	3.80	500	505	495
3			5	5.1	4.75	600	610	600
4			6	6.15	5.8	700	710	705
5			7	7.3	7.0	800	830	815

Table 5.4: Field performance indices (measured)

Measured indices	**Mean values**
Mean crop yield	1,300kg/ha
Pre harvest loss	40kg/ha
Crop moisture content at harvest	21% - 15.6%
Height of the crops	55cm – 90cm
Weight of grains left unstripped on the stubble	18.8g/plot
Weight of grains left unstripped on lodged crops	11.4g/plot
Weight of materials other than grains (MOG) stripped	16.8g/plot
Weight of total grains and MOG stripped	288.1g/plot
Weight of grains found in quadrat (shattered loss)	22.9g/plot
Maximum wind velocity at time of harvest	2.34m/s
Time taken to reap a plot	14.3s/plot
Weight of grains threshed during harvest	255.2g/plot

Table 5.5: Field performance indices (computed)

Computed indices	**Mean values**
Shattering loss	6.9%
Cracked grain loss	0.0%
Lodging loss	3.4%
Stubble loss	5.7%
Crop purity	89.7%
Total grain loss	15.9%
Fuel consumption rate	8.4ml/plot
Effective harvester field capacity	0.044ha/h
Harvester field efficiency	56.68%
Harvester efficiency	78%

Table 5.6: Summary of Analysis of Variance for data generated in the 2x5x5 factorial experiment (performance evaluation)

Source of variation	Degree of freedom	Computed F – Values[1]									
		Shattered loss	Stubble loss	Lodging loss	Total loss	Time spent	Fuel consumed	Field capacity	Grain purity	Field efficiency	Harvester efficiency
Replication	2	1.05	13.02**	1.11	3.03	10.60**	20.39**	22.30**	3.28	3.72	4.54
Treatment	49	1.43	1.41	0.84	0.98	2.77	2.04	2.38	1.17	1.60	0.09
Rotor height, R	1	8.23	0.10	0.66	0.46	0.39	0.38	0.74	4.20	1.01	0.01
Forward speed, U	4	0.38	1.49	0.81	0.42	11.88**	2.56	4.08	1.07	4.41	0.38
Stripper rotor speed, V	4	1.98	0.49	2.36	1.66	0.23	0.27	0.56	1.61	0.33	1.16
R∗U	4	0.69	1.57	0.07	0.05	0.38	0.50	0.49	1.27	0.26	0.41
R∗V	4	0.70	0.47	0.85	0.56	1.42	1.40	2.27	0.95	0.44	0.16
U∗V	16	1.70	1.26	0.80	1.19	2.12	1.44	1.51	0.93	1.98	1.16
R∗U∗V	16	1.28	0.60	0.69	0.86	1.87	1.32	1.38	0.91	1.25	0.63
Error	98										
Total	149										

1 ** Significant at 1% level (highly significant)

* Significant at 5% level (significant)

Table 5.7: Duncan multiple range test result of the mean separation

	Time spent(s)	Other Times (s)	Fuel (ml)	Total Stripped (g)	Clean Grain (g)	Unthreshed Grain (g)	MOG (chaff)(g)	Shattered loss (g)
R								
1	14.41[a]	10.80[a]	8.32 [a]	3026.67 [a]	279.33 [a]	6.08 [a]	17.26 [a]	20.73 [a]
2	14.15 [a]	11.53 [a]	8.47 [a]	277.29 [a]	256.80 [a]	4.13 [a]	16.36 [a]	25.07 [a]
SE ±	0.30	0.45	0.18	8.54	8.03	0.43	0.91	1.07
U								
1	14.80[b]	11.07[a]	8.54[ab]	312.07[a]	288.61[a]	5.85[a]	17.61[a]	22.22[a]
2	13.27[c]	11.00[a]	8.00[b]	289.93[ab]	266.05[ab]	5.69[a]	18.19[a]	22.20[a]
3	16.50[a]	11.03[a]	9.09[a]	290.64[ab]	269.41[ab]	4.20[a]	17.03[a]	23.06[a]
4	12.17[c]	12.10[a]	8.01[b]	252.59[b]	232.59[b]	5.36[a]	14.73[a]	24.66[a]
5	14.76[c]	16.67[a]	8.36[ab]	269.56[ab]	248.65[ab]	4.42[a]	16.49[a]	22.38[a]
SE ±	0.48	0.70	0.28	13.5	12.73	0.68	1.44	1.69
V								
1	14.06[a]	11.33[a]	8.36[a]	283.50[ab]	260.54[ab]	5.03[ab]	17.93[a]	22.47[ab]
2	14.40[a]	11.80[a]	8.65[a]	285.43[ab]	263.83[ab]	4.07[b]	17.53[a]	24.89[a]
3	14.50[a]	10.70[a]	8.32[a]	315.54[a]	294.11[a]	3.91[b]	17.52[a]	23.81[ab]
4	14.07[a]	11.00[a]	8.27[a]	255.81[b]	233.84[b]	6.17[a]	15.80[a]	18.96[b]
5	14.43[a]	11.00[a]	8.39[a]	277.10[ab]	255.48[ab]	6.36[a]	15.26[a]	24.38[a]
SE ±	0.48	0.70	0.28	13.5	12.74	0.68	1.44	1.69
Interaction								
R*U	NS	NS	NS	NS	NS	NS	NS	NS
SE ±	0.68	1.0	0.40	19.09	18.03	0.96	2.04	2.39
R*V	NS	NS	NS	NS	NS	NS	NS	NS
SE ±	0.68	1.0	0.40	19.09	18.03	0.96	2.04	2.39
U*V	*	NS	NS	NS	NS	NS	NS	NS
SE ±	1.07	1.58	0.63	30.18	28.51	1.52	3.23	3.78
R*U*V	*	NS	NS	NS	NS	NS	NS	NS
SE ±	1.51	2.23	0.89	42.68	40.32	2.15	4.56	5.35

	Stubble Loss(g)	Lodging Loss(g)	Total loss(g)	Total yield (g)	Field Capacity (ha/h)	Field efficiency (%)	Grain purity (%)	Harvester efficiency (%)
R								
1	19.04[a]	11.84[a]	51.62[a]	337.03[a]	0.045[a]	57.39a[a]	89.76[a]	79.58[a]
2	18.58 [a]	10.97[a]	53.60[a]	314.53[b]	0.044[a]	55.97[a]	89.71[a]	76.40[a]
SE ±	1.01	0.75	2.06	8.73	0.09	1.0	0.45	1.01
U								
1	19.24[ab]	9.77[a]	51.23[a]	345.69[a]	0.0043[ab]	57.94[ab]	90.06[a]	80.43[a]
2	18.58[cb]	12.71[a]	53.48[a]	325.22[a]	0.047[a]	55.29[ac]	89.19[a]	77.60[ab]
3	17.68[ab]	11.52[a]	52.36[a]	325.97[a]	0.040[b]	60.34[a]	90.33[a]	79.17[a]
4	21.87[c]	11.86[a]	55.73[a]	293.59[a]	0.048[a]	51.65[c]	89.43[a]	74.70[a]
5	16.68[b]	11.17[a]	50.25[a]	303.32[a]	0.044[ab]	58.16[ab]	89.66[a]	78.05[a]
SE ±	1.61	1.20	3.27	13.87	0.015	1.58	0.78	1.43
V								
1	20.12[a]	9.92[b]	49.96[a]	315.52[ab]	0.045[a]	56.11[a]	89.30[a]	78.27[a]
2	19.16[a]	12.29[ab]	56.34[a]	324.24[ab]	0.043[a]	55.69[a]	90.21[a]	77.61[a]
3	19.07[a]	9.63[b]	52.52[a]	350.54[a]	0.046[a]	57.79[a]	90.89[a]	79.80[a]
4	17.09[a]	11.07[ab]	47.0[a]	287.15[b]	0.045[a]	56.34[a]	88.82[a]	78.28[a]
5	18.62[a]	14.10[a]	57.10[a]	318.94[ab]	0.044[a]	57.48[a]	89.46[a]	75.98[a]
SE ±	1.61	1.20	3.27	13.87	0.015	1.58	0.78	1.43
Interaction								
R*U	NS	NS	NS	NS	NS	NS	NS	NS
SE ±	2.27	1.69	4.63	19.62	0.027	2.29	1.02	1.75
R*V	NS	NS	NS	NS	NS	NS	NS	NS
SE ±	2.27	1.69	4.63	19.62	0.027	2.29	1.02	1.75
U*V	NS	NS	NS	NS	NS	*	NS	NS
SE ±	3.6	2.67	7.32	31.02	0.036	3.58	1.59	2.49
R*U*V	NS	NS	NS	NS	NS	NS	NS	NS
SE ±	5.09	3.78	10.36	43.87	0.046	5.0	2.56	4.97

∗- significant at 5% level, ∗∗- Highly significant at 1% level, N.S – Not significant.
Means with different letters are significantly different in the groupings

Table 5.8: Comparison of mechanical harvester with manual Harvesting using student's 't' test

S/No	Parameters	Harvesting methods		Calculated t-value	Table t-value	Level of significance
		Mechanical	Manual			
1	Mean loss, % of total yield	13.5	20.27	2.14	1.75	*
2	Mean time spent per plot, seconds	14.3	120	13.0	2.60	**

*- significant at 5% level

**- Highly significant at 1% level

n.s – Not significant

Table 5.9: Rice stripper optimum settings of critical operating parameters

S/No	Parameters	At rotor height 270mm	At rotor height 220mm
1	Harvester forward speed	3km/h	4km/h
2	Stripper rotor speed	670rpm	560rpm
3	Harvester nose height above ground	530mm	480mm
4	Field capacity	0.078ha/h	0.075ha/h
5	Fuel consumption rate	27.6 litre/ha	26.6 litre/ha
6	Harvester efficiency	81%	77%
7	Grain purity	90.2%	87.5%
8	Threshed grains, percent of total stripped	97.5%	92.7%

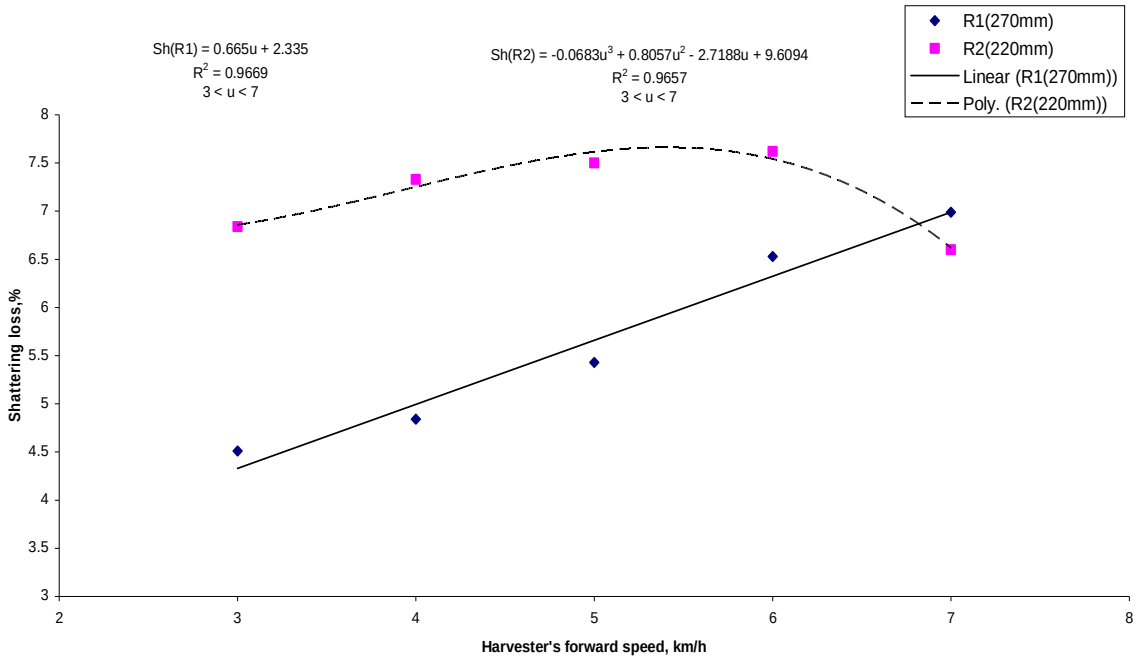


Figure 5.1a: Effect of harvester's forward speed on shattering loss at two levels of rotor height.

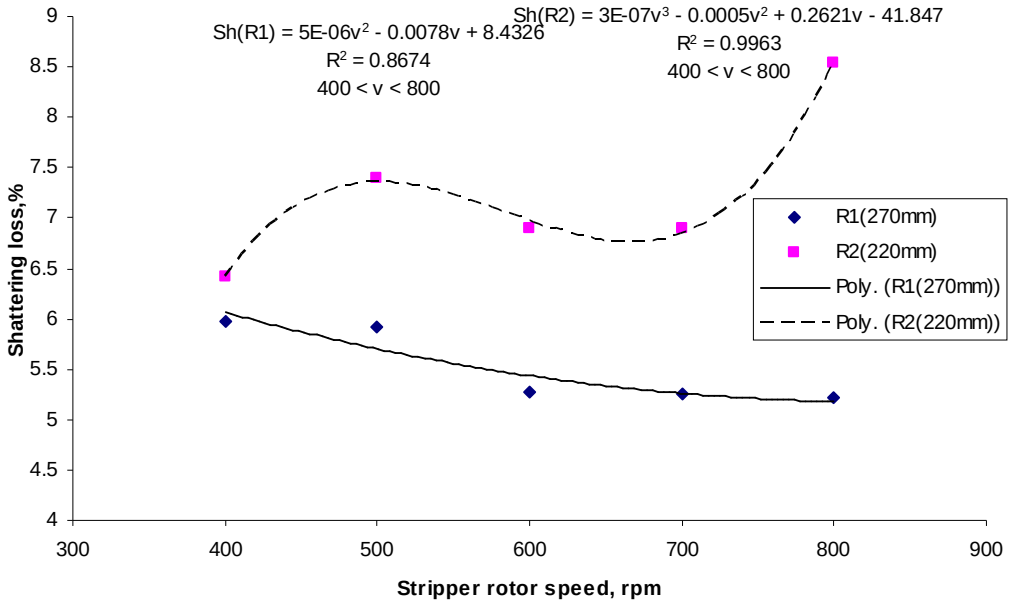


Figure 5.1b: Effect of stripper rotor speed on shattering loss at two levels of rotor height.

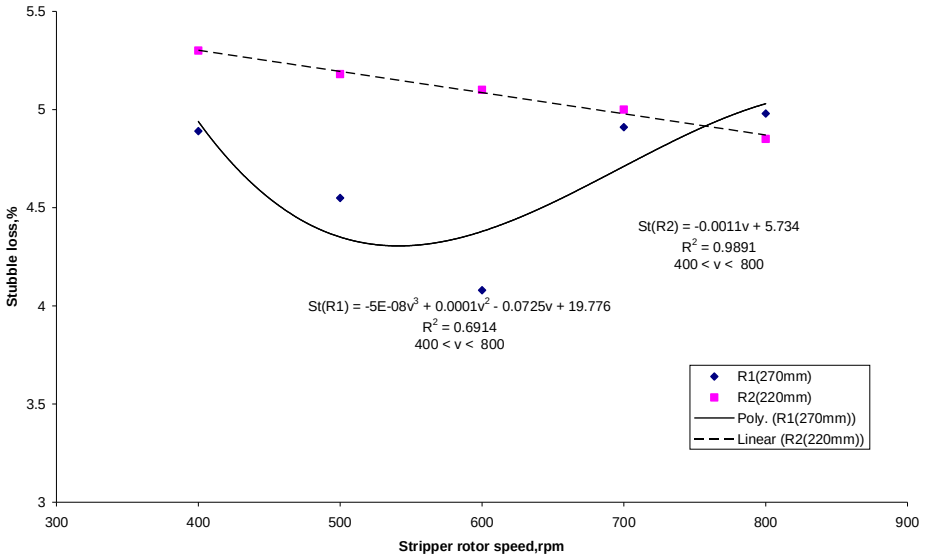


Figure 5.2a: Effect of stripper rotor speed on stubble loss at two levels of rotor height .

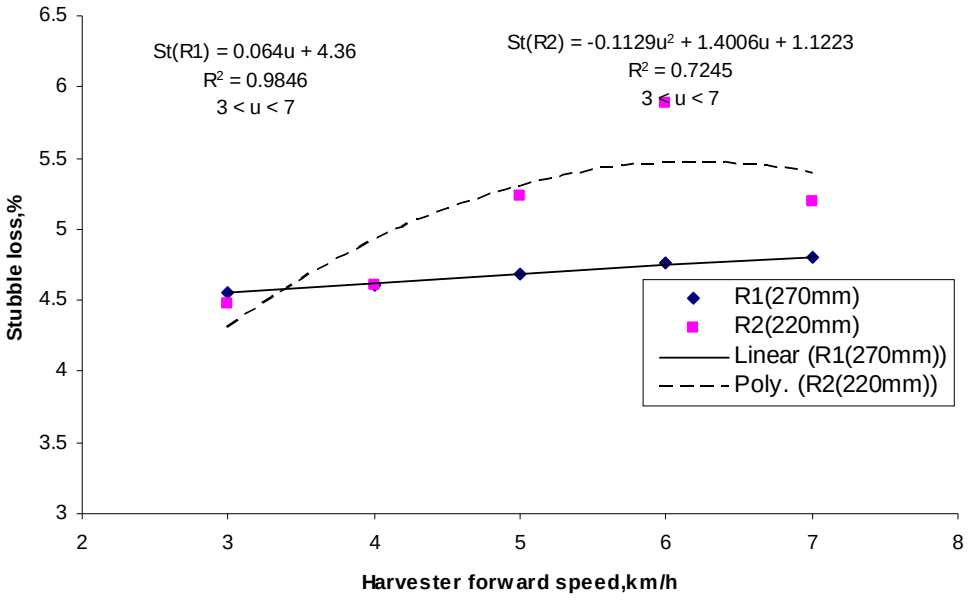


Figure 5.2b: Effect of harvester's forward speed on stubble loss at two levels of rotor height.

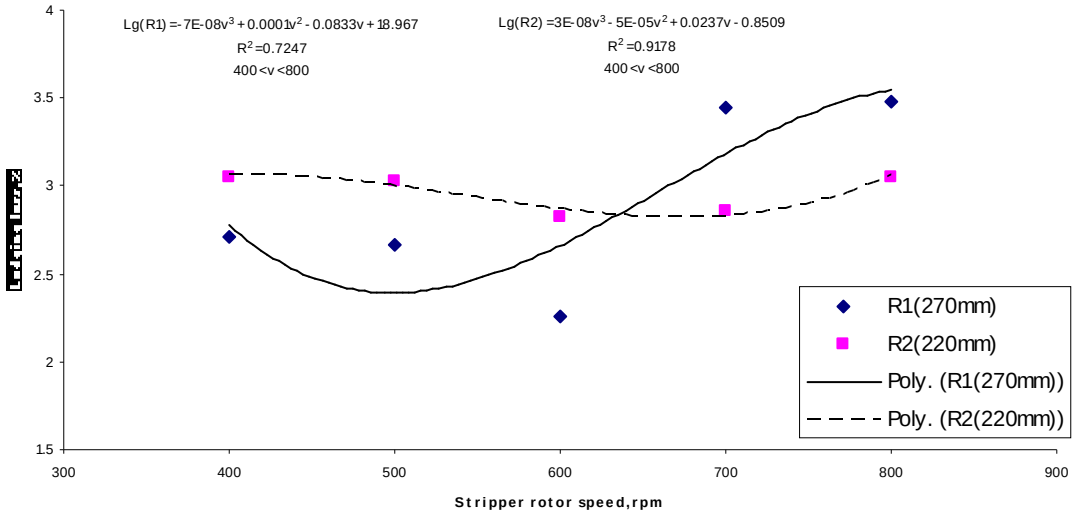


Figure 5.3a: Effect of stripper rotor speed on lodging loss at two levels of rotor height .

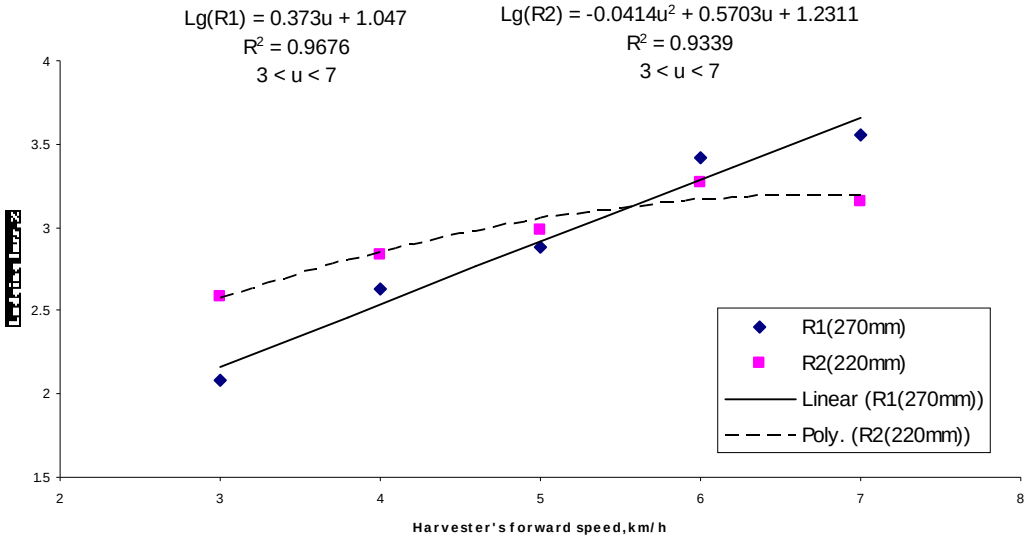


Figure 5.3b: Effect of harvester's forward speed on lodging loss at two levels of rotor height.

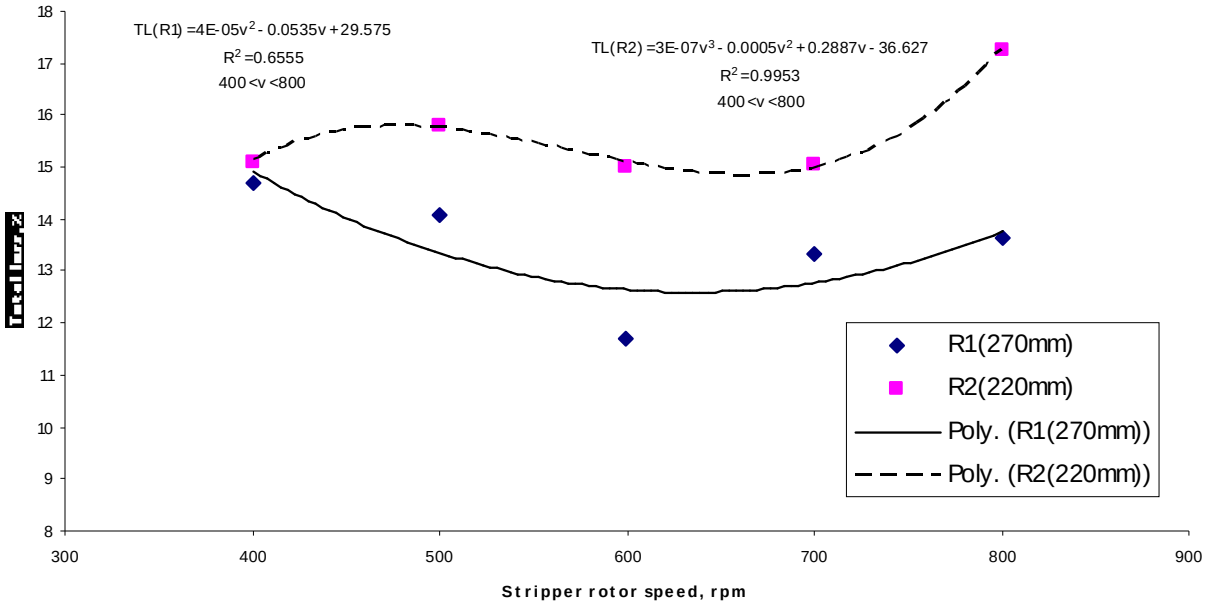


Figure 5.4a: Effect of stripper rotor speed on total loss at two levels of rotor height.

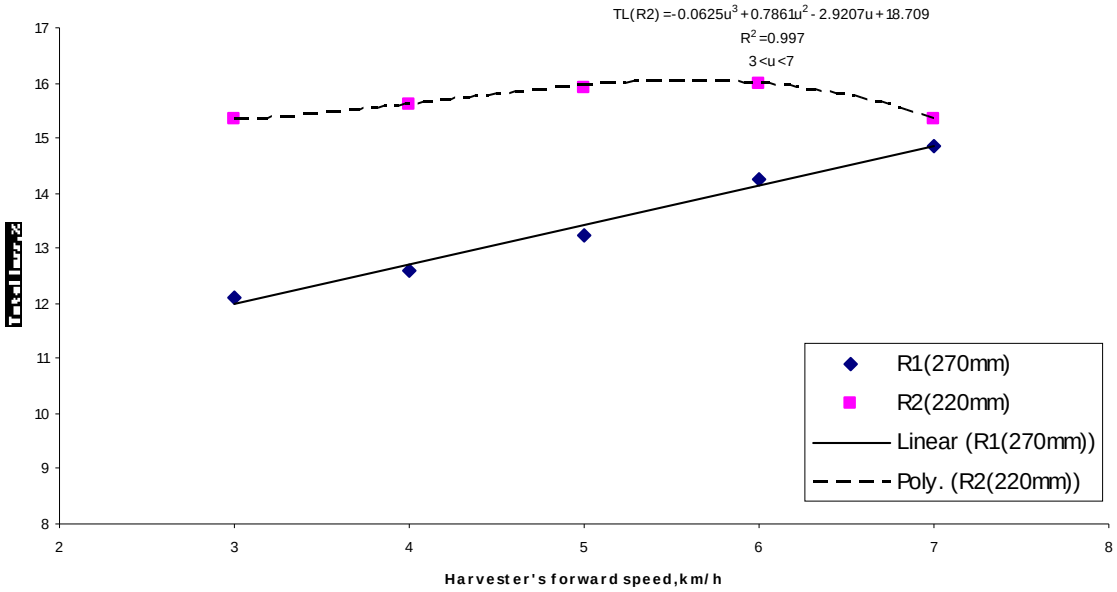


Figure 5.4b: Effect of harvester's forward speed on total loss at two levels of rotor height.

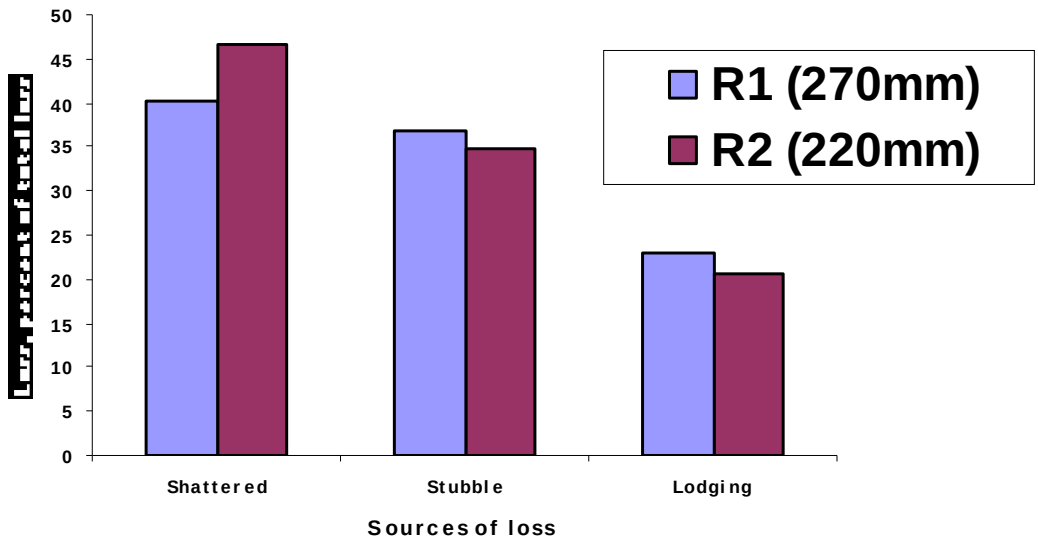


Figure 5.5: Contribution of the various sources of loss to the total loss in a 2x5x5 factorial experiment.

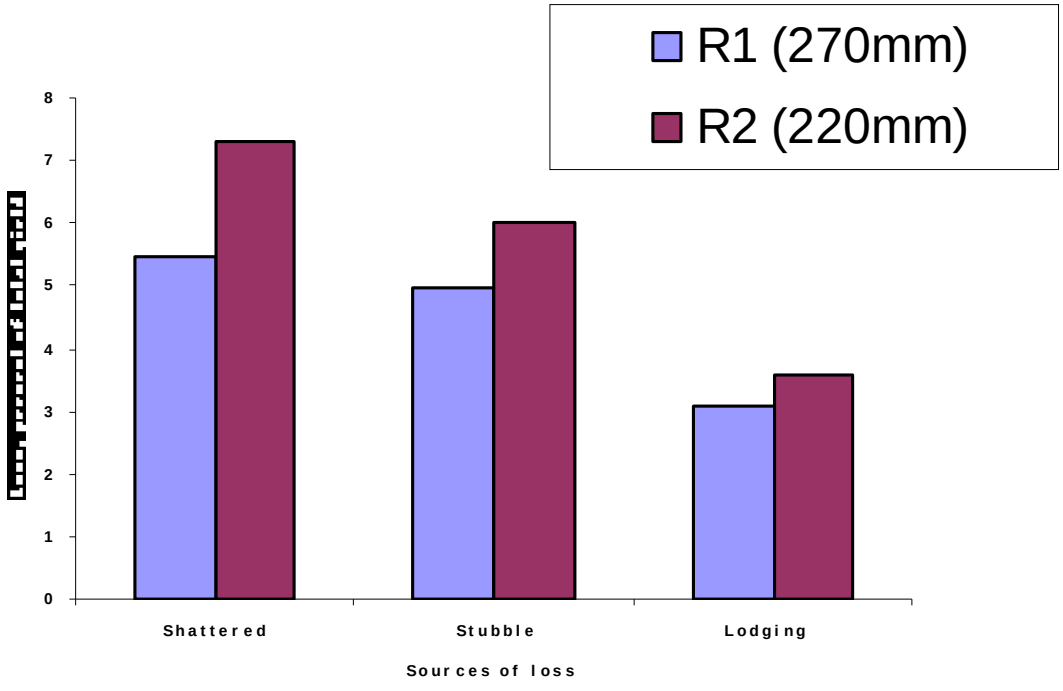


Figure 5.6: Contribution of the various sources of loss in a 2x5x5 factorial experiment

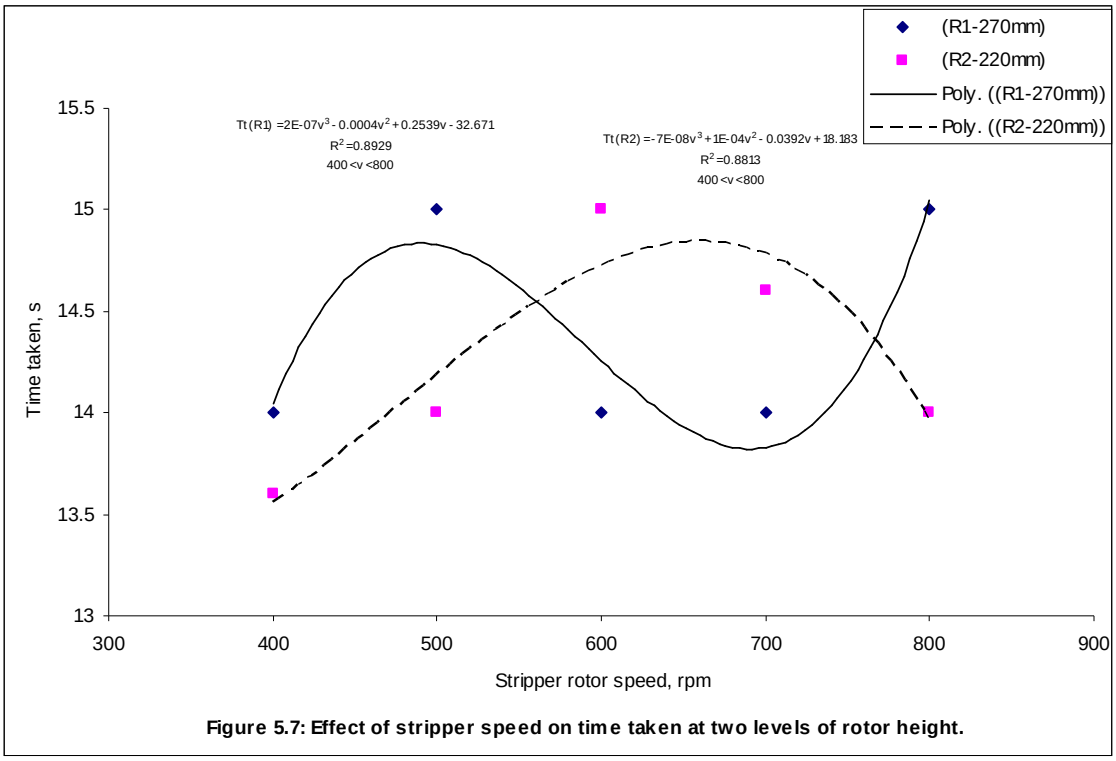


Figure 5.7: Effect of stripper speed on time taken at two levels of rotor height.

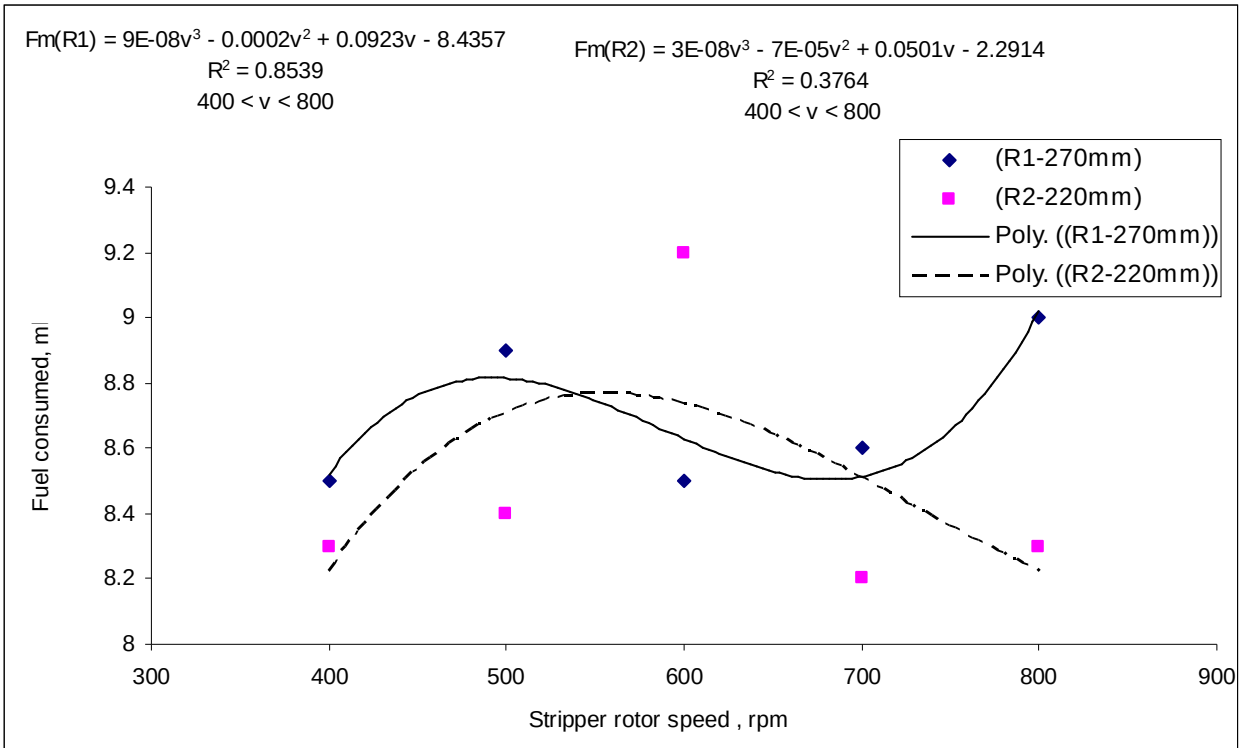


Figure 5.8: Effect of stripper rotor speed on fuel consumption at two levels of rotor height.

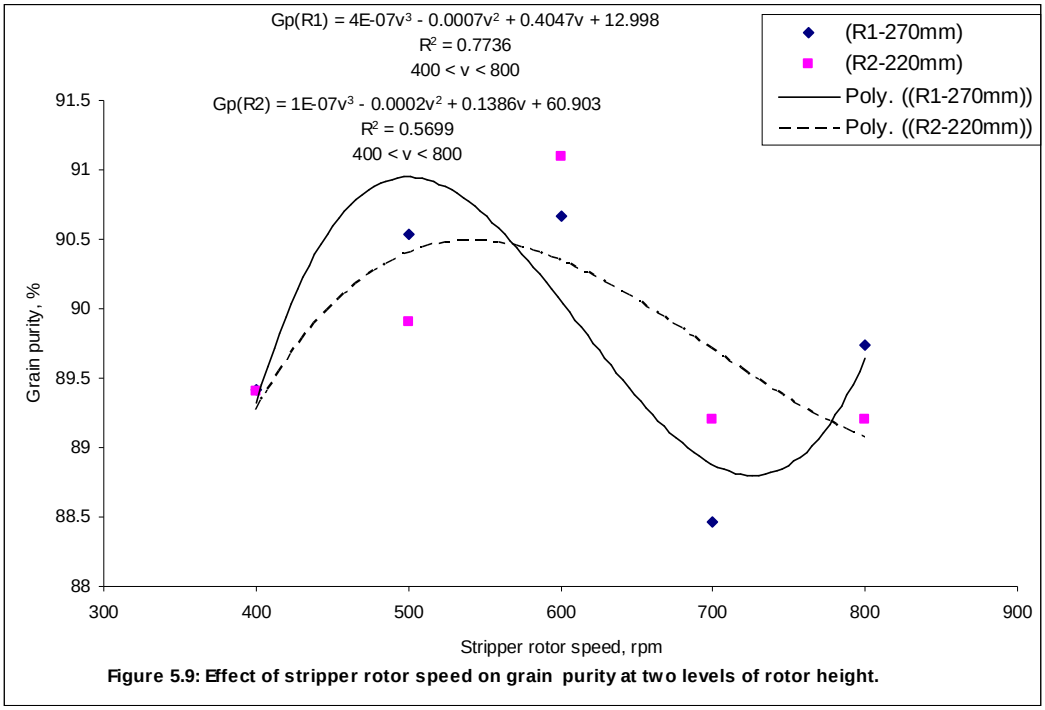


Figure 5.9: Effect of stripper rotor speed on grain purity at two levels of rotor height.

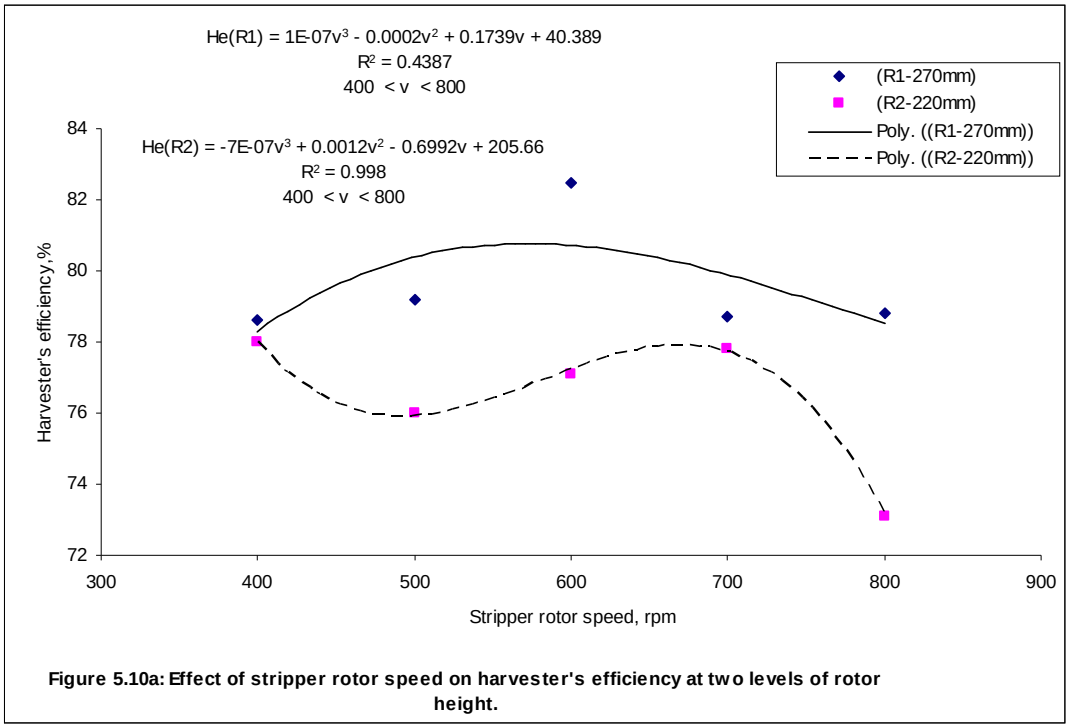


Figure 5.10a: Effect of stripper rotor speed on harvester's efficiency at two levels of rotor height.

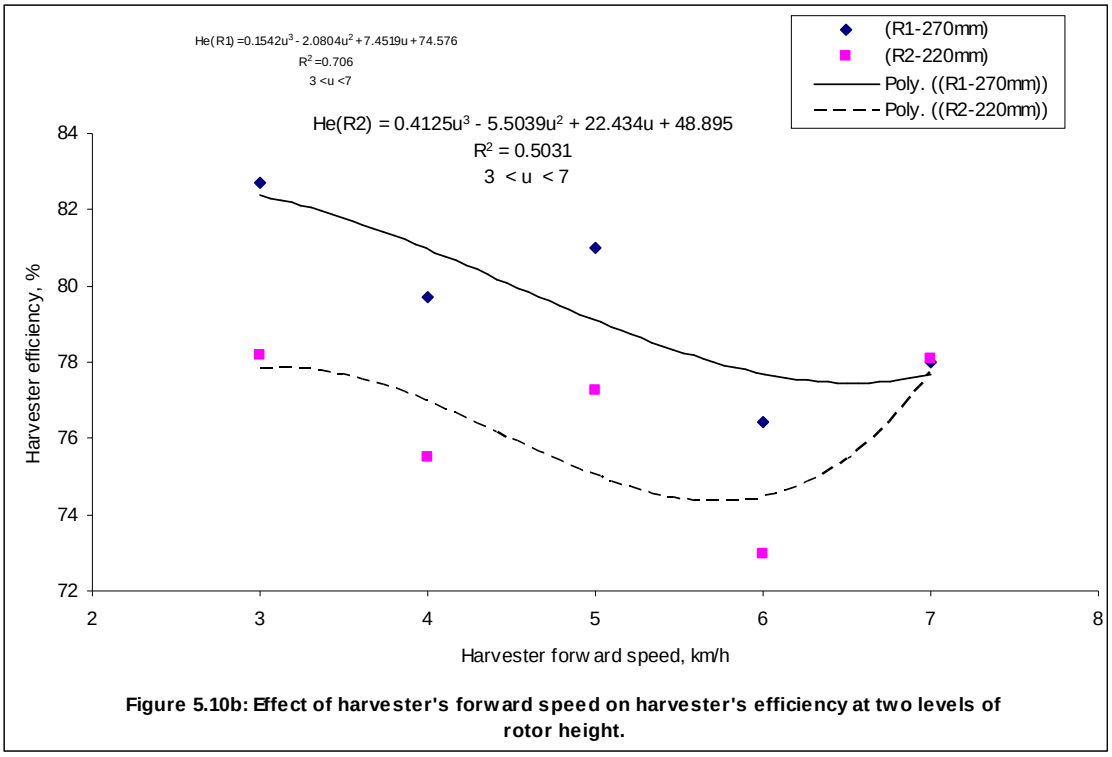


Figure 5.10b: Effect of harvester's forward speed on harvester's efficiency at two levels of rotor height.

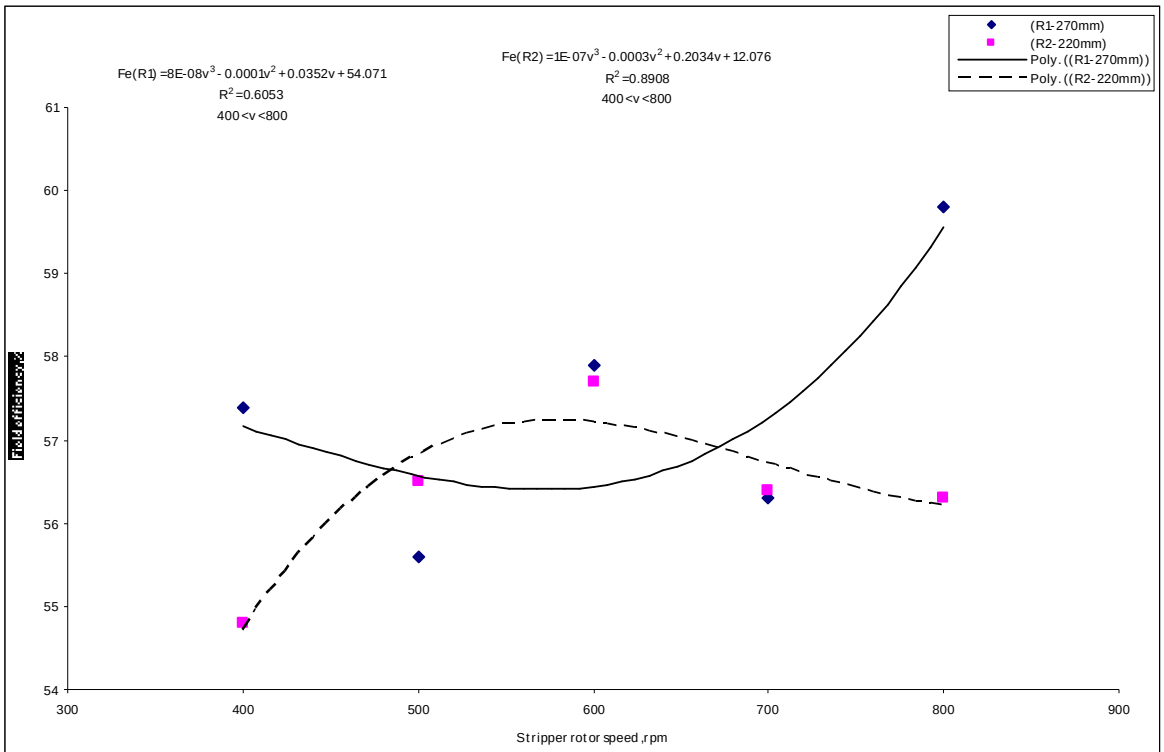


Figure 5.11: Effect of stripper rotor speed on field efficiency at two levels of rotor height.

5.2 Discussions

5.2.1 Measured machine design physical properties

Table 5.1 is the outcome of machine design physical properties measured. The values of standard deviation of plant spacing 4.24 and crop yield 15.81 are high due to non-uniformity in manual planting spacing and soil fertility. Also the standard deviation values of crop height 8.94, bulk density 9.49 and number of tillers per hill 2.13 were high because it was discovered that the seed materials used in planting were not totally pure. The standard deviation value of crop moisture content at harvest 2.85 was also high because the harvesting was not done in a day but took 7 days, therefore the crop moisture content varied rapidly within the period.

5.2.2 Pitch diameters of pulleys

Table 5.2 which is the preliminary test result carried on the machine in the workshop shows that when a constant pulley size 73mm diameter was fixed on the first idler, decreasing the stripper pulley diameter size results in increasing the stripper rotor speed. Also the table shows that when a constant pulley size of 45mm diameter was fixed on the second idler, decreasing the front wheel shaft pulley diameter size results in increasing the machine forward speed. A constant pulley diameter sizes were fixed on second idler and auger shaft to obtain its only speed of 150 rpm.

5.2.3 Values of the harvester's settings

The values of designed rotor heights above ground 300mm and 200mm as in Table 5.3 came to be 270mm and 220mm respectively when the machine was in field operation due to stripper rotor horizontal adjustment made on the field for proper stripping. Table 5.3 also shows the designed forward speed to be 2, 4, 5, 6, 7km/h which came to be 2.75, 3.8, 4.75, 5.8 and 7.0 km/h respectively due to non-uniformity of the ground surface and obstructions by the crops plants along the path of the wheel movement. The stripper rotor designed speed of 400, 500, 600, 700 and 800 rpm became 400, 495, 600, 705 and 815 rpm respectively due to additional speed increase added to take care of the amount of speed decrease that occurred due to stripping operation and machine moving parts friction.

5.2.4 The field performance indices (measured)

From Table 5.4, mean crop yield was 1,300kg/ha and the pre-harvest loss was found to be 40kg/ha. The crop moisture content at harvest fell between 21% to 15.6% because it took 7 days to complete the field experiment. Also Table 5.4 shows the crop height was 55cm to 90cm which was an indication that the seed material used in planting was not pure and also non-uniformity in soil fertility. The shattered loss was 22.9g/plot, stubble loss was 18.8g/plot and lodging loss was 11.4g/plot showing lodging loss to be the least because there was no serious lodging

of crop on the rice field where the experiment was carried out. Very reasonable amount of total grains was stripped with MOG which came to be 288.1g/plot out of which 255.2g/plot of grains was threshed leaving very small unthreshed.

5.2.5 The field performance indices (computed)

Table 5.5 shows the mean values of the computed field performance indices with shattering loss 6.9% the highest, followed by stubble loss 5.7%, lodging loss 3.4% and cracked grain loss 0% out of the total loss of 15.9%. There was no cracked grain found among the stripped material because the stripping element was made of rubber and the inner hood surface on which the stripped grains bounced was linned with rubber carpet to reduce shattering loss due to grains rebounding. The grain purity was 89.7%, harvester field efficiency 56.68% and harvester efficiency was 78%. The harvester mean field capacity was 0.044ha/h which was low due to the small size of the machine stripping width 0f 30cm. The fuel consumption rate 8.4m/plot was high due to obstruction encountered by the machine with the crop stubbles on the field.

5.2.6 Result of analysis of variance and Duncan multiple range test of mean groupings

From Table 5.6, the ANOVA results showed that the replication

was highly significant for stubble loss, time spent, fuel consumed and field capacity. That is, the blocking was considered effective in reducing the experimental error since F(replication) was significant (Gomez and Gomez, 1976). The effect of variation in crop heights and ground gradient was responsible for the significance effects.

The values with the same letter from Table 5.7 above are not significantly different in their groupings while those with different letters in a group are significantly different. In the interactions, the NS means not significantly different while * indicate that the interactions are significantly different at 5% level and ** at 1% level. That is, time was significantly different on field efficiency, harvester speed, rotor speed interactions and rotor height.

5.2.7 Results of field experiment

The crop moisture content, varied from 21% to 15.6% on wet basis. The soil moisture content was averagely 11%, the height of crop varied from 55cm to 90cm and relatively stalk heads were stripped while what were left unstripped are shown as means of stubble loss (5.7%) and lodging loss (3.4%) in Table 5.5. Broken paddy grains was found to be 0% because the inner hood with which the fleeing stripped grains collided was lined with rubber carpet to reduce grain rebouncing (rechochetting). Tables 5.4 and 5.5 are the results of the measured and computed parameters from the field tests.

5.2.8 Effect of harvester settings on shattering loss

The result of analysis of variance (ANOVA) carried out on the data generated from the harvester performance field experiments showed that the harvester's forward speed and rotor speed did not show any significant effect on shattering loss.

Table 5.6 shows the summary of the result of the analysis of variance of data collected. Duncan Multiple Range Test (DMRT) Table 5.7 revealed two significant levels of means grouping for the stripper rotor speed with $V_{(}$700 rpm) having the lowest value for the means loss. This test (DMRT) also showed that the means of harvester forward speed have only one group of significant level with the lowest means value at U_2 (4km/h).

The test showed a non-significant difference in the means of shattered loss for the stripper rotor height. However, the graphs in Figures 5.1a and 5.1b shows that the shattering loss are more at stripper rotor height R_2 (220mm) which rose gradually up polynomially. The trend of shattering loss at stripper rotor height R_1 (270mm) increased linearly as the harvester speed increases in Figure 5.1a while it also polynomially rose as the harvester speed increases in Figure 5.1b. Generally, the shattering loss was higher at lower stripper rotor height. At harvester's forward speed 6.9km/h $R_1$and R_2 had the same shattering loss.

The regression equations and coefficients of multiple determination relating the harvester forward speed with the shattering

loss at two levels of rotor height are respectively given as follow:

$Sh(R_1) = 0.665u + 2.335$ .....(5.1)

$R^2 = 0.9669$

$Sh\ (R_2) = 0.0683u^3 + 0.8057u^2 – 2.7188u + 9.6094$..... (5.2)

$R^2 = 0.9657$

Where:

$Sh(R_1)$ and $Sh(R_2)$ are the shattered losses at rotor heights of 270mm and 220mm respectively (expressed as a percentage of the total yield)

U is the harvester forward speed, km/h

R^2 is the coefficient of multiple determination

Also relating the stripper rotor speed with shattered loss at two levels of rotor height, gave the regression equations and R^2 respectively as follow:

$Sh\ (R_1) = 5x10^{-6}v^2 – 0.0018v + 8.4326$..... (5.3)

$R^2 = 0.8674$

$Sh\ (R_2) = 3x10^{-7}v^3 – 0.0005v^2 + 0.2621v – 41.847$..... (5.4)

$R^2 = 0.9963$

Where V is the stripper rotor speed, rpm.

Sh (R_1) and (R_2) are the shattering losses at rotor heights 270mm and 220mm (percent of total yield)

With high values of R^2 it then means that both linear and polynomially regression models represent well the values of shattered

loss plotted as presented and explained by Figures 5.1a and 5.1b.

5.2.9 Effect of harvester's setting on stubble loss

Table 5.6 shows that both harvester's forward speed and stripper rotor speed did not show any significant effect on the stubble losses. Duncan Multiple Range Test (DMRT) Table 5.7 revealed one group of stubble loss for stripper rotor speed with least mean at V_4 (700rpm), the stubble loss value was 17.093g (4.4% of total yield) at stripper rotor height R_1, (270mm). The lowest stubble mean at R_2 (220mm) was 4.9% of total yield. This result shows that the (DMRT) revealed two groups of stubble loss for harvester's forward speed. The least mean occurred at U_3 (5km/h) the first group which was 17.683g (5% of total yield) for R_1 (270mm) and 5.5% for R_2 (220mm). The least mean occurred for the second group at U_5 (7km/h) which was 4.8% for R_1 (270mm) and 5.2% for R_2 (220mm).

Figures 5.2a and 5.2b further shows the trend of stubble losses as varied with stripper rotor speed and harvester forward speed. The losses showed both linear and polynomial trend of increase as stripper rotor and harvester forward speeds increases. At stripper rotor speed 760rpm, R_1 and R_2 had the same stubble loss and at harvester's forward speed 3.4km/h, R_1 and R_2 had the same stubble loss.

The regression models relating the stripper rotor speed with the stubble loss at two levels of rotor height are as given below:

$St(R_1) = -5x10^{-8}v^3 + 0.0001v^2 – 0.0725v + 19.776$ ..... (5.5)

$R^2 = 0.6914$

$St(R_2) = -0.0011v + 5.734$..... (5.6)

$R^2 = 0.9891$

Where:

$St(R_1)$ is the stubble loss (percent of total yield)at rotor height R_1, (270mm).

$St(R_2)$ is the stubble loss percent of total yield at rotor height R_2 (220mm)

The coefficient of multiple determination (R^2) are 0.6914 and 0.9891 respectively.

Estimated values of the stripper rotor speed for minimum stubble loss was obtained from the derivative of the regression models (equations 5.5 & 5.6) e.g

$\frac{\partial}{\partial v} St(R1) = - 3x5x10^{-8}v^2 + 2x0.0001v – 0.0725 = 0$

$\frac{\partial^2}{\partial v^2} St(R2) = -2x3x5x10^{-8}v + 2x0.0001 = 0$, i.e $V(R_1)= 667rpm$

Although the ANOVA had shown a non-significant effect of the stripper rotor speed on the stubble loss, figure 5.2a shows clearly the effect of stripper rotor speed on stubble loss. At the rotor height R_1 (270mm) the stubble loss fell initially and then polynomially rose up continuously as the rotor speed increases. In the case of rotor height setting at R_2 (220mm) it gradually linearly fell as speed of rotor speed

increases. This may be due to increase in the feed rate of the rice head to the stripper and to be taken in by the stripping unit.

The regression models relating the harvester's forward speed with the stubble loss at two levels of rotor height are as follow:

$St\ (R_1) = 0.064u + 4.36$.....(5.7)

$R^2 = 0.9846$

$St\ (R_2) = 0.1129u^2 + 1.4006u + 1.1223$..... (5.8)

$R^2 = 0.7245$

Where:

$St\ (R_1)$ and $St\ (R_2)$ are stubble losses (percent of total yield) at rotor heights, R_1 and R_2 respectively.

The coefficient of multiple determination (R^2) are 0.9846 and 0.7245 respectively for harvester's forward speed on stubble loss effect.

The graphs in Figure 5.2b shows linear increase of stubble loss as harvester speed increased for rotor height R_1 (270mm) setting while it was polynomial increase for height R_2 (220mm) setting. It is an indication of the harvester's forward speed effect on the stubble loss, that is, as the harvester forward speed increases, stubble loss increases. This was due to stripping hole distortation of stripper element at high speed because of the elements flexibility, hence some holes were enlarged while some closes and does not strip grain as it was supposed to do.

5.2.10 Effect of harvester's setting on lodging loss

The result of the analysis of variance presented in Table 5.6 is that the stripper rotor and harvester's forward speeds shown a non-significant effect on the lodging loss. DMRT Table 5.7 grouped the means of lodging loss for the stripper rotor speed in two.

The means for V_1 and V_3 (i.e 400rpm and 600rpm) were not significantly different and the lowest mean being in this group at V_3 (600rpm). DMRT grouped the lodging loss means into one with the least at U_1 (3km/h) for the harvester's forward speed. Figure 5.3a showed the trend of the lodging losses under the influence of stripper rotor speed. When rotor height was set at R_1 (270mm) the loss fell polynomially before it began to increase as the rotor speed increases. At rotor height setting R_2 (220mm), as the rotor speed increases, there was no much changes in the losses until it got to about 700rpm before it increases polynomially. At stripper rotor speed 640 rpm, R_1 and R_2 had the same lodging loss as shown in Figure 5.3a. Figure 5.3b shows both linear and polynomial increase of lodging as the harvester's forward speed increases. This was due to high feed rate of materials to the stripping and dislodging units which had lesser time to strip the dislodged rice heads. R_1 and R_2 at harvester's forward speed 5.5km/h had the same lodging loss and same at 640rpm rotor speed.

The regression equations relating the lodging loss to the stripper rotor speed at two levels of rotor height are given below:

$Lg(R_1) = -7x10^{-8}v^3 + 0.0001v^2 – 0.0833v + 18.967$ .....(5.9)

$R^2 = 0.7247$

$Lg(R_2) = 3x10^{-5}v^3 – 5x10^{-5}v^2 + 0.00237v – 0.8509$.....(5.10)

$R^2 = 0.9178$

$Lg(R_1)$ and Lg (R_2) are lodging losses (percent of total yield)at rotor height R_1 and R_2 respectively

The regression equations relating the lodging loss to the harvester speed at two levels of rotor height are given below:

$Lg(R_1) = 0.373u + 1.047$.....(5.11)

$R^2 = 0.9676$

$Lg(R_2) = -0.0414u^2 + 0.5703u + 1.2311$.....(5.12)

$R^2 = 0.9339$

The coefficients of multiple determinations (R^2) are all reasonably high and within acceptable values.

5.2.11 Effect of harvester's settings on total loss

The result of the analysis of variance presented in Table 5.6 and Duncan grouping, Table 5.7 did not show that both the stripper rotor speed and harvester's forward speed have high significant effect on the total loss. Figure 5.4a showed the trend with which the total loss increased polynomially with the rotor speed. The minimum total loss occurred at R_1 (270mm) of rotor height setting which was 556rpm and 669rpm before it both increased again.

The regression equations relating the loss to the stripper rotor speed at the two levels of rotor height are given below:

$TL(R_1) = 4x10^{-5}v^2 – 0.0535v + 29.575$.....(5.13)

$R^2 = 0.6555$

$TL(R_2) = 3x10^{-7}v^3 – 0.0005v^2 + 0.2887v – 36.627$.....(5.14)

$R^2 = 0.9953$

$TL(R_1)$ and $TL(R_2)$ are total loss at R_1, and R_2 expressed as percentage of total loss respectively as affected by rotor speed. The coefficients of multiple determination (R^2) are 0.6555 and 0.9953 respectively.

The regression models relating the total loss to the harvester forward speed at two levels of rotor height are given below:

$TL(R_1)$ $0.718u + 9.822$.....(5.15)

$R^2 = 0.9858$

$TL(R_2) = -0.0625u^3 + 0.7861u^2 – 2.9207u + 18.709$..... (5.16)

$R^2 = 0.997$

$TL(R_1)$ and $TL(R_2)$ are total loss as affected by harvester's forward speed at R_1 and R_2 expressed as percentage of total loss respectively.

The coefficients of multiple determination (R^2) are 0.9858 and 0.997 respectively.

Figure 5.4b shows how the total loss increases both linearly and polynomially as the harvester's forward speed increased. This was as a result of combined effects of machines behaviour under varied speed

feeding rate of stripping unit and rotor height in relation to crop height.

Duncan Multiple Range Test have the same grouping for both stripper rotor speed and harvester's forward speed. The minimum total loss mean occurred at stripper rotor speed V_4 (700rpm) which was 13.5% of total yield at R_1 (270mm) rotor height settings. It occured at harvester's forward speed U_5 (7km/h) and lowest total loss mean been 14.3% of total yield at rotor height setting R_1 (270mm).

The histograms or bar charts in Figures 5.5 and 5.6 shows the contributions of the various sources of loss discussed in sections 5.2.8 to 5.2.11. Figure 5.5 shows that the shattering loss contributed the highest of 40.2 percent to the total loss at a rotor height R_1(270mm) while the shattered loss also had the highest contribution of 46.6 percent of the total loss for rotor height R_2 (220mm). Figure 5.6 showed the histogram of the contributions of the various sources of loss computed as a percentage of total yield. The shattered loss was more pronounced, contributing about 5.46 percent of the total yield at rotor height R_1(270mm) and 7.28 percent at rotor height R_2 (220mm), Appendix C1. This was closely followed by stubble loss, contributing 4.97 percent of total yield at rotor height R_1(270mm) and 6.02 percent of total yield at rotor height R_2(220mm). The losses due to lodging was 3.08 percent of total yield at rotor height R_1(270mm) and 3.57 percent of total yield at rotor height R_2(220mm).

Duncan grouping had shown that there was no significant

difference in the means of shattering stubble and lodging losses at two rotor height. Figures 5.5 and 5.6 further showed that the losses due to lodging of crops was affected by the settings as the mean values obtained are though almost equal for both rotor heights, that is 3.08 and 3.57 percent of total yield for 270mm and 220mm respectively but lesser at 270mm.

5.2.12 Harvester settings for minimum loss

Harvester loss reduction programme must be focused on losses due to shattering, stubble and lodging as indicated in Klinner et al., (1987). Ichikawa (1981) found that these losses are usually affected by crop moisture content at the point of harvest with shattering loss more at lower moisture content. When the crop approached technological maturity, the strength of the stalk holding the grains to the stem weakened and as the moisture content further reduced, the stalk is weakened further. Grain detachment force depends on the crop stalk and grain moisture content, thickness of the stalk at point of detachment, maturity stage of crop, condition of detaching mechanism and other factors.

The best period for once over mechanical harvesting is when the crop has gained its maximum solid matter and attained technological maturity. Stout and Cheze (1999) recommended the best moisture content to harvest a ripe paddy rice as when it falls within 14% to 27%

with ideal value at about 20% on wet basis. This researcher harvested at moisture content that ranged between 16% and 21%.

From Figures 5.1a, 5.1b, 5.2b, 5.3a, 5.3b and 5.6 the shattered and lodging losses were generally lower at rotor height R_1(270mm). At this rotor height the lowest lodging loss can be obtained at stripper rotor speed 476rpm and harvesters forward speed 3km/h. For rotor height R_2(220mm), the minimum lodging loss was obtained at estimated stripper rotor speed 556rpm and 6.9km/h harvester forward speed. The minimum shattering loss was obtained at estimated stripper rotor speed 780rpm and 3.5km/h harvester forward speed at rotor height R_1(270mm). It was 556rpm stripper rotor speed and 3.9km/h harvester forward speed at rotor height R_2(220mm).

The minimum stubble loss can be achieved (Figures 5.2a and 5.2b) at rotor height setting at R_1(270mm) when stripper rotor speed was 667rpm and 4.6km/h harvester's forward speed. With the stripper rotor height setting at R_2(220m), minimum stubble loss occurred at 800rpm of stripper rotor speed and 6.2km/h of harvester forward speed.

The minimum total loss was obtained at rotor height 270mm and estimated values of stripper rotor speed were 669rpm and 3km/h harvester forward speed corresponding to ($R_1U_1V_4$). At rotor height 220mm the estimated values of stripper rotor speed 556rpm and 4.2km/h harvester forward speed corresponding to ($R_2U_2V_3$).

Hence operating the harvester at these settings ($R_1U_1V_4$) would

bring the shattering loss to the barest minimum of 5.46%, stubble loss was 4.9% and lodging loss was 3.08 of total yield respectively. Operating at ($R_2V_2V_3$) gave shattering loss as 7.28%, stubble loss as 6.02% and lodging loss as 3.57 of total yield. Kalsirisilp and Singh (2001) tested this same similar rice stripping machine in Thailand and got the shattering loss to be 5.3%, stubble loss as 4% and 5.6% lodging loss of the total yield. Klinner et al (1987) got overall losses that ranged between minimum of 4.3% and as high as 10.7% of the total yield on his machine tested in England on some cereal crops.

5.2.13 Effect of harvester's settings on the time taken

Table 5.6 showed that the harvester's forward speed had a very high significant effect on the time spent to reap a plot. Harvester forward speed was significantly affected by time taken as shown by the ANOVA result. The R^2 values obtained for the graph of time spent plotted against harvester's forward speed was far below acceptable values, harvesting. This was due to the nature of the field condition, hindering occasionally the movement of the machine during harvesting. Figure 5.7 is the graph of time spent against stripper rotor speed which followed the trend of polynomial form.

The regression models relating the time taken to harvest each plot and stripper rotor speed at the two levels of rotor height are given below:

$$Tt(R_1) = 2x10^{-7}v^3 - 0.0004v^2 + 0.2539v - 32.671 \quad (5.17)$$

$R^2 = 0.8929$

$Tt(R_2) = - 7x10^{-8}v^3 + 1x10^{-4}v^2 – 0.0392v + 18.183$.....(5.18)

$R^2 = 0.8813$

Where:

$Tt(R_1)$and $Tt(R_2)$ are the times taken (seconds)on each plot and at different stripper rotor speed.

R^2 are 0.8929 and 0.8813 respectively.

The effective field capacity from equation (4.10) is a direct function of the time taken to reap each plot. Hence, at the optimum harvester setting as discussed in section (5.2.12) of rotor height 270mm, stripper rotor speed was 667rpm and harvester forward speed 3km/h, the average time spent on each plot was 13.9seconds. At the rotor height 220mm setting the stripper rotor speed was 556rpm and 4.2km/h harvester's forward speed, the average time spent on each plot was then 14.4 seconds (Appendix C5). This implies that the effective field capacities were 0.078 and 0.075 ha/h, respectively as computed from equation (4.10).

5.2.14 Effect of harvester's settings on energy consumed

The ANOVA Table 5.6 did not show any degree of significant effect on the energy consumed during harvesting except for the replication. The DMRT Table 5.7 was of the same grouping for stripper rotor speed but of two groups for harvester's forward speed with lowest values of 8.27ml

and 7.99ml of fuel consumed respectively. Figure 5.8 confirmed the significant effect of the stripper rotor speed. Fuel consumption rate at ($R_1V_1V_4$) and ($R_2U_2V_3$) were 27.6 litres/ha and 26.6 litres/ha respectively. At a harvester setting represented by ($R_1U_1V_4$) a single operator would be required to completely harvest 0.624ha of paddy rice within 8 hour working day.

5.2.15 Effect of harvester's settings on harvested grain purity, harvester field capacity and harvester efficiency

Figure 5.9 shows the polynomial trend of harvester grain purity (percentage of total yield) with varied stripper rotor speed. At stripper rotor speeds 580rpm and 780rpm the grain purity were the same at stripper rotor height 270mm and 220mm.

The ANOVA result Table 5.6 showed a non-significant effect of grain purity and the DMRT Table 5.7 were of one group for both stripper rotor speed and harvester forward speed. The minimum grain purity 88.7% was obtained here while Yulai et al (1999) obtained 85% on their stripper machine tested in China. Figures 5.10a and 5.10b shows the polynomial trend behaviour of the harvester efficiency in relation to both stripper rotor speed and harvester's forward speed. In Figure 5.10b the harvester efficiency polynomially decreased as the harvester forward speed increased. The highest harvester efficiency occurred at stripper rotor speed 667rpm with 270mm rotor height setting which was 81% and

571rpm at 220mm rotor height which was 77%.

The regression models relating the harvester efficiency to stripper rotor speed at two levels of rotor height are given below:

$He(R_1) = 1x10^{-7}v^3 – 0.0002v^2 + 0.1739v + 40.389$..... (5.19)

R^2 0.4387

$He(R_2) = -7x10^{-7}v^3 + 0.0012v^2 – 0.6992v + 205.66$.....(5.20)

$R^2 = 0.998$

Where:

He (R_1) and He(R_2) are harvester efficiencies (percent of clean plus unthreshed grain stripped to total yield) at two rotor height respectively as affected by rotor speed. The regression models relating the harvester efficiency to harvester forward speed at two levels of rotor height given as below:

$He(R_1) = 0.1542u^3 – 2.0804u^2 + 7.4519u + 74.576$.....(5.21)

$R^2 = 0.706$

$He(R_2) = 0.4125u^3 – 5.5039u^2 + 22.43u + 48.895$.....(5.22)

$R^2 = 0.5031$

Where:

He(R_1) and He(R_2) are harvester efficiencies (percent of clean and unthreshed grain stripped to total yield) at two rotor heights respectively as affected by harvester forward speed. The R^2 values are low in some cases which is what was been reflected in the nature of the graphs of equations (5.19 and 5.22). Figure 5.11 shows the polynomial trend of

harvester field efficiency as been affected by stripper rotor speed. At stripper rotor speed 480rpm and 670rpm the values of field capacities are the same at R_1 and R_2.

The regression models relating the harvester field efficiency to stripper rotor speed at two levels of rotor height as given below:

$Fe(R_1) = 8x10^{-8}v^3 – 0.0001v^2 + 0.0352v + 54.071$.....(5.23)

$R^2 = 0.6053$

$Fe(R_2) = 1x10^{-7}v^3 – 0.0003v^2 + 0.2034v + 12.076$.....(5.24)

$R^2 = 0.8908$

The coefficient of multiple determination are 0.653 and 0.8908 respectively.

Where:

$Fe(R_1)$ and $Fe(R_2)$ are harvester field efficiencies as related to stripper rotor speed at two levels of rotor height.

5.2.16 Comparison between harvester and manual harvesting

Table 5.8 is the result of comparison between harvester and manual harvesting. Comparing mean values of harvester and manual harvesting losses shows that the means were significantly different at 5% level in Table 5.8. Also ‘t’ test result’s of comparing mean values of the time spent for these two harvesting methods shows that the needs were significantly different at 1% level. The ‘t’ test value was high for time spent because the stripper performed four operations at one overall

mechanically including lifting, stripping, threshing and grains/MOG transporting in 14.3 seconds while the manual took 120 seconds to do this. Also the manual harvesting had higher loss of 20.27% than the 13.5% of the machine because a lot of losses were experienced during manual threshing that goes away with the chaff and broken paddy kernels.

5.2.17 The rice stripper optimum settings of critical operating parameters

Table 5.9 is showing the result of the best settings for the harvester at the two rotor heights 270mm and 220mm. From the table, the best machine settings was at 270mm rotor height, stripper rotor speed 670rpm and forward speed of 3km/h gave the field capacity to be 0.078ha/h, harvester efficiency was 81%, grain purity was 90.2% and percent of threshed grains was 97.5% in the total grain stripped results as shown. The settings of the rotor height at 220mm forward speed at 4km/h and rotor speed at 560rpm gave field capacity to be 0.075ha/h, harvesting efficiency was 77%, grain purity was 87.5% and threshed grains was 92.7%.

5.3 The Total Costs of Harvesting with the Harvester and Manual Labour

Total production cost of the pedestrian controlled stripper rice header together with the prime mover was seventy-eight thousand nine

hundred and fifty-five naira only (₦78,955.00). The details of the machine cost production estimate are provided in Appendix B1. Effective field capacity of the harvester at least loss settings was 0.078ha/h (section 5.2.12).

Depreciation cost (DP_{ha})was 455.5₦/ha.

Total interest chargeable per hectare (I_{ha})was 170.2₦/ha.

Tax, insurance, and shelter (TIS_{ha})cost per hectare was 98.9₦/ha.

Repair and maintenance cost per hectare (RMC_{ha})was 247.5₦/ha.

At fuel consumption rate of 26 litres/ha, the fuel cost (FC_{ha})was 1,820₦/ha

Labour cost per day for machine operator was 200 naira per day, hence, laobour cost (LC_{ha})per hectare was 313.4₦/ha

The total cost of harvesting (TC_{ha})with pedestrian controlled stripper rice header was 3,105.5₦/ha.

Information from National Agricultural Seed Council, IAR Samaru, Zaria showed that a labourer can reap 0.5ha per day from which 7 bags of 100kg paddy rice was obtained at a cost of ₦1,700 and it cost ₦1,400 to thresh and clean the seven bags by two farm hands a day to harvest, thresh and clean one hectare. By this extension, the cost of manually harvesting one hectare of paddy rice was ₦6,200.00 at this time.

The manual power consumed as measured was 36W to harvest 3m^2 and it will then amount to 120kw to harvest one hectare.

The above analysis shows that it was evidently clear that the

harvester, pedestrian controlled rice stripping header, has succeeded in reducing the cost of harvesting rice by about 50%. Number of workers required and the duration of rice harvesting has been reduced, giving chance for more available labourers and time to carryout other farming activities during this harvesting period.

CHAPTER SIX

6. SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

Rice has become a staple food in Nigeria homes and the local supply was found to be far below the demand, hence efforts is to be directed towards increasing its production quantity and quality. Manual harvesting results in higher grains losses and poorer quality than the machine harvested apart from drudgery involved in manual harvesting which is predominant among Nigeria farmers.

The majority of the present day Nigeria farmers are grouped as those who are still in use of traditional farming tools like hoes, machetes, knives, sickles and scythes because of their low level of education, technical skill and income earners. To increase farm production, suitable alternative mechanization skills ad equipment must be made available to these farmers. The physiological properties of rice crop harvesting under this study showed that the crop height and lodging effect were part of mechanical harvesting index with rice profuse root type for good root/soil holding capacity, compact grain panicle head and crop height below or above 1m.

Considering the low skill and low per capital income of majority of Nigeria farmers, an alternative equipment to replace manual rice harvesting must not be sophisticated in production and operation and cheap enough for the farmers to operate and own. Stripper hearder's

technology was found simple, the size of which can be produced as small as possible to maneuver in the small parcel rice field. The grain stripper detaches grains from the stalk at high speed and moves the stripped materials into the harvester's collection box.

A pedestrian controlled rice stripper harvester was designed and fabricated to reap rice. The major functional units were the stripper rotor, the screw auger, a collecting box, the power transmission system, steering unit, traction, furrow divider, dislodging hook and a prime mover. Performance of this harvester was evaluated on an upland Faro 44 rice field locally called Kwadala variety, mostly cultivated at Basawa in Zaria and its environment.

A randomized complete block design (RCB) was adopted to study the effect of stripper rotor heights at various harvester forward speeds and stripper rotor speeds on field losses, harvester grain purity, fuel consumption, field capacity and harvester efficiency.

The experimental results showed that the harvester forward speed had very high significant effect on time taken to harvest each plot. The stripper did the stripping with insignificant mechanical damage to the grain. The stripped materials, the grains and matters other than grains (MOG) were well conveyed into the grain box at the lower end from where the screw auger was able to discharge it at the end of each plot harvesting.

6.2 Conclusions

From the study, the following conclusions can be drawn:

- The harvester harvested rice by stripping grains with the straw left behind which can be removed for other usage or plowed into the soil.
- The harvester maneuvered easily at the end of each plot on small parcel field.
- The machine harvested 0.62 ha/day by one operator with minimum threshing and cleaning left (97.5% grain threshed) and to a large extent reduced drudgery associated with manual harvesting which should have taken 3 farm hands to accomplish in a day.
- Cost of harvesting with this machine reduced to 50% of manual harvesting.

6.3 Recommendations

With reference to the results of the performance evaluation of the pedestrian controlled rice stripper, the following recommendations are hereby made:

- The use of other local stripper materials other than the motor tyre linning rubber material should be investigated.

- The furrow divider mechanism should be further worked upon for better furrow demarcation between stripped and the unstripped furrow.
- Trials of the stripper harvester on fadama for rice and other crops like wheat, barley and soyabeans is hereby recommended.
- The machine width of stripping could be increased to increase the harvester field capacity.

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APPENDICES

TABLE A1: COMBINED SHOCK AND FATIGUE FACTOR ON SHAFT

	Km (Factor for bending moment)	**Kt (factor for Torsional moment)**
For stationary shafts;		
Load gradually applied.	1.0	1.0
Load suddenly applied.	1.5 to 2.0	1.5 to 2.0
For rotating shafts:		
Load gradually applied.	1.5	1.0
Load suddenly applied (minor shock).	1.5 to 2.0	1.0 to 1.5
Load suddenly applied (heavy shock).	2.0 to 3.0	1.5 to 3.0

Source: Hall et al., (1980)

TABLES A2 SELECTION AND DIMENSIONS OF V-BELTS[4]

Normal	**Motor speed, rev/min**			
Horsepower	1,800	1,200	900	⊆ 720
0.5 to 1.5	A	A	A	A
2 to 5	A or B	A or B	A or B	A or B
10	A or B	B	B	B or C
15	B	B or C	B or C	C
20	B or C	C	C	C
25 to 30	C	C	C	C
40	C	C or D	C or D	D
50 to 60	C or D	C or D	C or D	D
75	C or D	C or D	C or D	D or E
100	C	D	D	D or E
125	.....	D	D	D or E
150 to 200	.....	D	D	E
250	.....	E	E	E
300 and over	.....	.....	E	E
Section	A	B	C	D E
Width, in.	0.5	0.65625	0.875	1.25 1.5
Thickness in	0.3125	0.40625	0.53125	0.75 0.9065

4 source Black and Adam (1982) PP 281

Table A3: ANGLE OF CONTACT FOR BELTS

Belt	Value of factor C_α at an angle of contact of							
	70^0	**80^0**	**90^0**	**100^0**	**110^0**	**120^0**	**130^0**	**140^0**
Flat	–	–	–	–	–	0.82	0.85	0.88
V	0.56	0.62	0.68	0.74	0.78	0.93	0.86	0.89
Belt	**Value of factor C_α at an angle of contact of**							
	150^0	**160^0**	**170^0**	**180^0**	**190^0**	**200^0**	**20^0**	**220^0**
Flat	0.91	0.94	0.97	1.00	1.05	1.10	1.12	1.15
V	0.92	0.94	0.98	1.00	–	–	–	–

Source: Black and Adam (1982)

Table A4: Power transmitted by narrow series V-belts

Diameter of small pulley	Transmitted power (kw) (per belt) at n, rpm				
	950		**1450**		**2800**
		Section NO at L_0 = 1.6m			
63	0.78-0.88		1.08-1.23		1.74-2.02
71	0.99-1.10		1.40-1.55		2.29-2.58
80	1.24-1.33		1.74-1.90		2.90-3.19
90	1.50-1.60		2.13-2.28		3.55-3.84
		Section NA at L_0 = 2.5m			
90	1.70-1.92		2.35-2.69		3.64-4.29
100	2.11-2.33		2.94-3.28		4.64-5.28
112	2.60-2.82		3.65-3.98		5.79-6.44
125	3.12-3.34		4.39-4.73		6.99-7.65
		Section NB at L_0 = 3.55m			
140	4.29-4.75		5.90-6.61		8.54-9.86
160	5.47-5.93		7.58-8.24		10.9-12.3
180	6.62-7.09		9.20-9.86		13.0-14.4
200	7.80-8.24		10.7-11.4		14.8-16.1
		Section NC at L_0 = 5.6m			
224	11.3-12.4		14.9-16.7		15.2-18.6
250	13.6-14.8		18.0-19.7		16.3-20.3
280	16.3-17.4		21.2-22.9		17.4-20.8
315	19.1-20.3		24.6-26.3		–
The smaller values or P_0 correspond to u = 1.2, the larger to u ≥ 3.					

Source: Black and Adams (1982)

Table A5: DYNAMIC LOAD AND SERVICE FACTOR

Kind of load	Type of machine	Factor k
Steady, starting load 120% of normal load	Electric generators, fans, centrifugal pumps and compressor, belt conveyers, machine tools with continuous cutting action: lathes, drills, grinders etc.	1
Moderately variable load starting load 150% of normal load	Piston pumps and compressors with three or more cylinders, apron conveyers, automatic lathes, etc	1.1
Considerably variable load. Starting load 200% of normal load	Reversing drives, planners, shapers and slotters, piston pumps and compressors with one or two cylinders, screw and drag-bar conveyers, elevators, screw and eccentric presses with comparatively heavy flywheels etc	1.25
Shock and severely non-uniform loads. Staring load 300% of normal load	Hoists, excavators, dredges, eccentric and screw presses with comparatively light flywheel, shears, power hampers, sand mullers, grinding mills etc	1.5-1.6
Note: For frequent and sudden starts of motors with high starting torques, factor K should be increased by 0.15. for two-shift duty, factor k should be increased by 0.15; for three shift duty, by 0.35		

Source: Black and Adams (1982)

Table A6: V- BELTS GROOVE ANGLES[7]

Belt section	Weight Lb per ft	Pitch diameter small sheave	Groove angle, β^0	Coefficient of friction
A	0.06	Under 3	30	0.50
		3 – 5	34	0.45
		Over 5	38	0.40
B	0.106	Under 5.4	30	0.50
		5.4 – 8	34	0.45
		Over 8	38	0.40
C	0.20	Under 9	30	0.50
		9 – 12	34	0.45
		Over 12	38	0.40
D	0.40	Under 13	30	0.50
		13 – 16	34	0.45
		Over 16	38	0.40
E	0.60	Under 21.6	30	0.50
		21.6 - 24	34	0.45

7 Source: Black and Adam (1981) PP 283

Table A7: **V – BELT SERVICE FACTORS[5]**

Equipment	**Factors**
Agitatiors, paddle propellers	1.0 – 1.2
Bakery machinery	1.0 – 1.2
Flour, feed, and cereal mills	1.0 – 1.4
Machine tools Conveyors	1.0 – 1.4 1.0 – 1.5
Generators and exciters, laundry machines	1.2
Paper machinery and printing machinery	1.2
Compressors	1.2 - 1.4
Screens	1.2 – 1.4
Brick and clay machinery	1.2 – 1.6
Oil-field machinery	1.2 – 1.6
Textile machinery	1.2 – 1.8
Fans and blowers	1.2 – 2.0
Pumps	1.2 – 2.0
Crushing machinery	1.4 – 1.6
Mills	1.4 – 1.6
Line shafts	1.4 – 2.0
Rubber plant machinery	1.4 – 2.0
Recommended size of driving sheave[6]	
Section Minimum pitch	**Recommended range of small pitch diameter, inches**
A 3.0	3.0 – 5.0
B 5.4	5.4 – 7.4
C 9.0	9.0 – 13.0
D 13.0	13.0 – 17.0
E 21.0	21.0 – 28.0

5 Source: Black and Adam (1981) PP 283

6 Source: Black and Adam (1981) PP 283

Table A8: Cross-sectional dimension and length of V – Belts

Type	Section	b_d, mm	b_0 mm	h, mm	H_0, mm	A, cm2	Design length limits, mm	D min, mm	Application for torque T* kgf-m
Standard	O	8.5	10	6	2.1	0.47	400-2500	63	<2.5
Series (USSR	A	11	13	8	2.8	0.81	560-4000	90	1.1-7
Std GOST	B	14	17	10.5	4.0	1.38	800-6300	125	4-19
1284-68	C	19	22	13.5	4.8	2.30	1800-10600	200	11-55
	D	37	32	19	6.9	4.76	3150-15000	315	45-200
	E	32	38	23.5	8.3	6.92	4500-18000	500	110-450
	F	42	50	30	11.0	11.70	6300-18000	800	>220
	NO	8.5	10	8	2.0	0.56	630-3550	63	–
Narrow	NA	11	13	10	2.8	0.93	800-4500	90	–
Series (USSR	NB	14	17	13	3.5	1.59	1250-800	140	–
Std PTM	NC	19	22	18	4.8	2.78	2000-8000	224	–
51-15-70									
*T is the torque on the high speed pulley									

Source: Black and Adam (1982)

TABLE A9: VALUES OF SERVICE FACTOR M_s

S/No	Type of service	Service factor (M_s) for radial ball bearings
1	Uniform and stead load	1.0
2	Light shock load	1.5
3	Moderate shock load	2.0
4	Heavy shock load	2.5
5	Extreme shock load	3.0

Source: Khurmi and Gupta (2006)

Table A10: BASIC STATIC AND DYNAMIC CAPACITIES OF VARIOUS TYPES OF RADIAL BALL BEARINGS.

Bearing No	Basic capacities in KN							
	Single row deep groove ball bearing		Single row angular contact ball bearing		Double row angular contact ball bearing		Self-aligning ball bearing	
	Static (C_0) (2)	Dynamic (C) (3)	Static (C_0) (4)	Dynamic (C) (5)	Static (C_0) (6)	Dynamic (C) (7)	Static (C_0) (8)	Dynamic (C) (9)
200	2.24	4	–	–	4.55	7.25	1.80	5.70
300	3.60	6.3	–	–	–	–	–	–
201	3	5.4	–	–	5.6	8.3	2.0	5.85
201	4.3	7.65	–	–	–	–	3.0	9.15
302	3.55	6.10	3.75	6.30	5.6	8.3	2.16	6
302	5.20	8.80	–	–	9.3	14	3.35	9.3
203	4.4	7.5	4.75	7.8	8.15	11.6	2.8	7.65
303	6.3	10.6	7.2	11.6	12.9	19.3	4.15	11.2
403	11	18	–	–	–	–	–	–
204	6.55	10	6.55	10.4	11	16	3.9	9.8
304	7.65	12.5	8.3	13.7	14	19.3	5.5	14
404	15.6	24	–	–	–	–	–	–
205	7.1	11	7.8	11.6	13.7	17.3	4.25	9.8
305	10.4	16.6	12.5	19.3	20	26.5	7.65	19
405	19	28	–	–	–	–	–	–
206	10	15.3	11.2	16	20.4	25	5.6	12
306	14.6	22	17	24.5	27.5	35.5	10.2	24.5
406	23.2	33.5	–	–	–	–	–	–
207	13.7	20	15.3	21.2	28	34	8	17
307	17.6	26	20.4	28.5	36	45	13.2	30.
407	30.5	43	–	–	–	–	–	–
208	16	22.8	19	25	32.5	39	9.15	17.6
308	22	32	25.5	35.5	45.5	55	16	35.5
408	37.5	50	–	–	–	–	–	–
209	18.3	25.5	21.6	28	37.5	41.5	10.2	18
309	30	41.5	34	45.5	56	67	19.6	42.5
409	44	60	–	–	–	–	–	–
210	21.2	27.5	23.6	29	43	47.5	10.8	18
310	35.5	48	40.5	53	73.5	81.5	24	50
410	50	68	–	–	–	–	–	–

Source: Khurmi and Gupta, 2006

Table A11: TORQUES AND PROOF LOADS FOR COURSE-THREAD METRIC BOLTS

Size	Nearest English equivalence	Root area (mm^2)	Class 4.6 Minimum tensile strength 400 MPa		Class 8.8 minimum tensile strength 830 MPa		Class 9.8 Minimum tensile strength 900MPa		Class 10.9 minimum tensile strength 1040 MPa		Class 12.9 Minimum tensile strength 1220 MPa	
			Torque Nm	Proof load KN	Torque Nm	Proof load KN	Torque Nm	Proof load KN	Torque Nm	Proof load KN	Torque Nm	Proof load KN
2.0 2.5 3.0	3	2.1 3.4 5.0	0.14 0.28 0.51	473 763 1.13	0.37 0.76 1.35	1.26 2.04 3.00	0.40 0.82 1.47	1.35 2.20 3.27	0.52 1.06 1.88	1.74 2.82 4.15	0.61 1.24 2.21	2.01 3.29 4.88
3.5 4.0 5.0	6	6.8 8.8 14.2	0.80 1.18 2.39	1.53 1.98 3.20	2.13 3.15 6.36	4.08 5.28 8.52	2.31 3.41 6.90	4.41 5.71 9.23	2.96 4.38 8.86	5.64 7.30 11.8	3.47 5.14 10.99	6.58 8.52 13.8
6.0 6.3 8.0	¼	20.1 22.6 36.6	4.05 4.78 9.84	4.52 5.09 26.25	10.81 12.76 22.0	12.1 13.6 28.46	11.72 13.84 23.8	13.1 14.7 36.54	15.05 17.77 30.4	16.7 18.8 42.87	17.66 20.84 35.5	19.5 21.9
10.0 12.0 14.0	5/8	58.0 84.3 115.0	19.49 33.99 54.10	13.1 19.0 25.9	51.99 90.68 144.32	34.8 50.6 69.0	56.38 98.33 156.49	37.7 54.8 74.8	72.38 126.25 200.93	48.7 70.0 95.4	84.91 148.10 235.70	56.3 81.8 112
16.0 20.0 24.0	1-3/16	157.0 245.0 353.0	84.40 164.64 284.66	36.3 55.1 79.4	225.18 439.24 759.43	94.2 147 212	244.17 476.28 823.48	102 159 229	313.50 611.52 1057.31	130 203 293	367.76 717.36 1240.30	152 238 342
30.0 36.0 42.0	1-5/16	561.0 817.0 1120.0	565.49 988.24 1580.54	126 184 252	1508.64 2636.49 4216.66	337 490 672	1635.86 2858.85 4572.29	365 531 728	2100.38 3670.62 5870.59	466 678 930	2463.91 4305.92 6886.66	544 792 1086
		U.S. EQUIVALENT SAE2			SAE 5		SAE 6 & 7		SAE 8		SAE 9	
[a]Troque for zinc-coated fasteners												

Source: Krutz, et al., 1984.

Table A12: HEXAGON NUTS COARSE THREADS

Normal size MM	Nearest English	Class 5 Use class 4.6 bolts Proof load KN	Class 9 Use class 8.8 and 9.8 bolts Proof load KN	Class 10 Use class 8.8, 9.8, 10.9 bolts Proof load KN
2.0		1.18	1.36	2.15
2.5	3	1.93	3.05	3.52
3.0		2.87	4.55	5.23
3.5		3.86	6.10	7.05
4.0	6	5.00	7.90	9.13
5.0		8.09	14.1	14.8
6.0		11.4	19.9	20.9
6.3	¼	12.9	22.4	23.5
8.0		20.9	36.2	38.1
10.0		33.1	57.4	60.3
12.0	5/8	48.1	83.5	87.7
17.0		65.6	114	120
16.0		89.5	155	163
20.0	13/16	170	223	255
24.0		201	321	367
30.0		320	511	583
36.0	1-13/16	466	743	850
42.0		638	1020	1165

Source: Krutz, et al., 1984

Table A13: SUGGESTED TORQUE VALUES (ft lb)

Bolt or Nut size	Grade "5" Regular Nut		Grade "5" Prevailing Torque Nut	
	Nominal	Specified	Nominal	Specified
1/4 – 20	6	5 – 7	9	7 – 11
5/16 – 18	13	11 – 15	18	15 – 21
3/8 – 16	23	20 – 26	30	26 – 34
7/16 – 114	35	30 – 40	43	37 – 49
1/2 – 13	55	47 – 63	68	58 – 78
9/16 – 12	80	68 – 92	97	82 – 112
5/8 – 11	110	99 – 121	135	122 – 148
3/4 – 10	200	180 – 220	233	210 – 256
7/8 – 9	300	270 – 330	350	315 – 385
1 – 8	440	396 – 484	507	456 – 558
Tolerance of specific torque: 0 – 10ft lb ± 20% of nominal: 10 – 100ft lb ± 15% of nominal; 100 ft lb ± 10% of nominal				

Source: Krutz, et al., 1984.

B1 Cost Estimate of the Pedestrian Controlled Rice Stripper

Component	Component parts	Quantity	Material	Dimension	Unit price (₦)	Cost (₦)
Stripper	Stripper disc	2	BG22 MS plate	400mmx400mmx3mm	250.00	500.00
	Stripping elements	8	Rubber linning	300mmx125mmx6mm	150.00	1,200.00
	Covering plates	8	BG18 MS	215mmx300mmx1.8mm	50.00	400.00
	Shaft	1	Iron rod, MS	15mm dia.x500mm	200.00	200.00
	Bearing	2	–	ID15.4mm	200.00	400.00
	Bearing housing	2	–		150.00	300.00
	Bolts & nuts	8	–	M12	30.00	240.00
	Bolts & nuts	24	–	M8	20.00	480.00
	Stripper frame	2	Flat iron bar	350mmx50mmx5mm	350.00	700.00
	Cutting/joining/m		MS	–	850.00	850.00
	achining		–			
Frame	Flat bar iron frame	2	Mild steel	1,100mmx50mmx5mm	1,050.00	2,100.00
	Mainframe bracket	4	Mild steel	980mmx50mmx5mm	750.00	3,000.00
	Rear wheel frame	2	Mild steel	750mmx50mmx5mm	650.00	1,300.00
	bracket	1	Iron rod, MS	25mm dia. x 670mm	650.00	650.00
	Front wheel shaft	1	Iron rod, MS	15mm dia. x 240mm	175.00	175.00

	Rear wheel shaft Bearing Bearing housing Bolts & nuts	4 4 24	– – –	ID 25.4mmx215.4mm – M12	350.00 200.00 30.00	1,400.00 800.00 720.00
Front hood	Side and top covers Cutting/joining/machining	1	BG18 MS –	1,700mmx450mmx1.8mm –	650.00 1,950.00	650.00 1,950.00
Rear covers	Side, top & bottom covers Gain box Bolts & nuts Cutting/joining/machining	1 1 10	BG18 MS BG18 MS – –	3,100mmx600mmx1.8mm 1,000mmx40mmx1.8mm M8 –	1,450.00 230.00 20.00 1,200.00	1,4500.00 230.00 200.00 1,200.00

Conveyor	Screw auger	1	G1 pipe & MS	34.5mm dia. x 320mm	250.00	250.00
	Screw auger	1	BG18 MS	30mmx320mmx1.8mm	150.00	150.00
	housing	1	Iron rod MS	10mm dia. x 470mm	200.00	200.00
	Shaft	2	–	ID-10.2mm	150.00	300.00
	Bearing	2	–	–	100.00	200.00
	Bearing housing	6	–	M8	20.00	120.00
	Bolts & nuts	2	–	–	20.00	40.00
	Split pin		–	–	1,250.00	1,250.00
Furrow divider	Right &left furrow divider	4	BG22 Ms plate	360mmx60mmx3mm	750.00	3,000.00
Dislodging hook	Hook	3	Iron rod MS	8mm dia. x 400mm	100.00	300.00
	Hook frame	1	Iron rod MS	10mm dia. x 400mm	200.00	200.00
	Cutting/joining/machining				500.00	500.00
Steering unit	Steering pipe	1	G1 pipe	50mm dia. x 1,600mm	1,350.00	1,350.00
	Steering lock pin	1	Iron rod MS	8mm dia. x 120mm	20.00	20.00
	Cutting/joining/machining				850.00	850.00
Traction	Front tyres and	2	Pneumatic type	3.50 Rim 8 size	3,500.00	7,000.00

device	rims Rear tyre and rim Bolts & nuts	1 6		3.50 Rim 8 size M12	3,500.00 40.00	3,500.00 240.00
Idler	Idler shaft Bearing Bearing housing	2 4 4	Iron rod MS	22mm dia. ID.23mm	450.00 250.00 200.00	900.00 1,000.00 800.00
Power & power Transmission	Belts Pulleys Prime mover Tensioners pipes Tensioner pulleys Cutting/joining/machining	5 10 1 2 3	G1 pipe	60mm dia. x 1050mm	200.00 350.00 25,000.00 1,250.00 200.00 1,500.00	1,000.00 3,500.00 25,000.00 2,500.00 600.00 1,500.00
	Total					78,955

C1 Effect of harvester's forward speed and stripper rotor speed on shattered loss at two levels of rotor height

Shattered loss (percent of total yield)

	R_1 (270mm)						R_2 (220mm)					
	Rep. 1	Rep. 2	Rep. 3	Mean			Rep. 1	Rep. 2	Rep. 3	Mean		
				UV	U	V				UV	U	V
U_1V_1	2.10	4.96	2.70	3.25			4.51	7.47	4.60	5.53		
U_1V_2	5.95	5.95	5.03	5.64			3.00	7.08	5.85	5.31		
U_1V_3	7.16	6.44	4.92	6.17			4.52	4.14	9.23	5.96		
U_1V_4	5.47	3.14	3.79	4.13	U_1	V_1	8.82	6.06	11.4	8.67	U_1	V_1
U_1V_5	2.86	2.18	5.06	3.37	4.51	5.98	6.87	8.62	10.65	8.71	6.84	6.41
U_2V_1	3.64	8.66	4.93	5.74			6.83	9.62	4.52	6.99		
U_2V_2	2.17	4.47	11.07	5.90			4.94	6.09	6.17	5.73		
U_2V_3	6.85	1.46	2.17	3.49			9.53	9.71	5.64	8.29		
U_2V_4	1.31	4.61	2.17	3.49	U_2	V_2	7.42	2.05	11.75	7.07	U_2	V_2
U_2V_5	0.81	7.35	7.61	5.26	4.84	5.92	8.91	10.25	6.60	8.59	7.33	7.40
U_3V_1	4.50	6.37	6.87	5.91			4.95	6.26	4.29	5.17		
U_3V_2	3.77	3.44	9.32	5.51			7.25	10.34	7.87	8.49		
U_3V_3	6.15	2.74	6.12	5.00			4.20	6.31	7.50	6.00		

U_3V_4	1.90	7.11	5.64	4.88	U_3	V_3	9.84	3.96	4.49	6.10	U_3	V_3
U_3V_5	5.28	5.07	7.14	5.83	5.43	5.28	4.59	19.69	10.70	11.66	7.50	6.90
U_4V_1	7.29	4.04	4.42	5.25			8.52	4.03	8.32	6.96		
U_4V_2	6.22	5.98	7.36	6.52			10.22	6.59	5.31	7.37		
U_4V_3	9.16	5.33	5.59	6.70			10.30	11.24	4.94	8.83		
U_4V_4	7.36	9.61	5.37	7.45	U_4	V_4	8.47	8.67	9.87	9.00	U_4	V_4
U_4V_5	8.81	6.62	4.73	6.72	6.53	5.25	5.73	6.28	5.85	5.95	7.62	6.89
U_5V_1	9.50	8.43	21.25	9.73			5.33	7.95	8.89	7.39		
U_5V_2	4.56	4.80	8.78	6.05			11.66	8.00	10.70	12.12		
U_5V_3	7.31	3.87	3.89	5.03			5.43	7.24	3.63	5.43		
U_5V_4	7.50	7.57	2.73	5.94	U_5	V_5	2.37	1.47	6.97	3.61	U_5	V_5
U_5V_5	5.46	3.83	5.38	4.89	6.99	5.21	5.05	7.29	6.91	6.41	6.60	8.53

C2 Effect of harvester's forward speed and stripper rotor speed on stubble loss at two levels of rotor height

Stubble loss (percent of total yield)

	R_1 (270mm)						R_2 (220mm)					
	Rep. 1	Rep. 2	Rep. 3	Mean			Rep. 1	Rep. 2	Rep. 3	Mean		
				UV	U	V				UV	U	V
U_1V_1	8.55	3.44	3.86	5.29			6.68	6.12	6.43	6.41		
U_1V_2	3.39	4.69	4.05	4.05			3.83	5.13	1.40	3.45		
U_1V_3	8.95	2.25	3.66	4.96			4.82	2.91	5.31	4.35		
U_1V_4	4.88	4.38	4.28	4.52	U_1	V_1	4.85	6.51	5.20	5.52	U_1	V_1
U_1V_5	5.27	4.87	1.93	4.02	4.56	4.89	4.61	0.00	3.38	2.66	4.18	5.30
U_2V_1	4.60	5.26	5.45	5.10			2.98	3.82	1.38	2.73		
U_2V_2	5.87	5.76	2.09	4.57			7.36	6.69	1.62	5.22		
U_2V_3	5.10	3.26	0.92	3.09			4.75	8.14	2.66	5.18		
U_2V_4	4.07	4.89	5.11	4.69	U_2	V_2	3.6	4.90	5.59	4.70	U_2	V_2
U_2V_5	6.66	5.35	4.60	5.54	4.60	4.55	9.31	5.12	1.07	5.17	4.60	5.18
U_3V_1	5.29	7.62	2.58	5.16			4.75	4.59	6.64	5.33		
U_3V_2	7.38	5.24	2.32	3.98			4.50	7.14	1.20	4.28		
U_3V_3	4.17	4.9	4.03	4.37			4.70	10.37	4.76	6.61		

U_3V_4	7.01	3.79	6.59	5.80	U_3	V_3	6.86	3.19	4.75	4.93	U_3	V_3
U_3V_5	7.74	1.37	3.18	4.10	4.68	4.08	2.83	3.46	8.68	4.99	5.23	5.10
U_4V_1	5.30	4.80	1.00	3.70			7.43	7.13	3.21	5.92		
U_4V_2	6.97	6.26	5.08	6.10			5.01	6.45	7.38	6.28		
U_4V_3	5.04	2.58	6.24	4.62			8.34	6.34	4.45	6.38		
U_4V_4	4.19	4.01	3.08	3.76	U_4	V_4	4.20	5.23	5.78	5.07	U_4	V_4
U_4V_5	5.83	5.28	5.75	5.62	4.76	4.91	7.20	7.32	2.80	5.77		
U_5V_1	4.61	7.04	3.96	5.20			5.45	7.86	4.97	6.09		
U_5V_2	6.08	3.00	3.05	4.04			6.52	9.72	3.72	6.65		
U_5V_3	4.83	3.86	1.38	3.36			5.67	1.85	1.39	2.97		
U_5V_4	6.27	6.20	4.83	5.77	U_5	V_5	4.61	1.69	7.53	4.61	U_5	V_5
U_5V_5	9.62	4.33	2.98	5.64	4.8	4.98	3.92	6.41	6.66	5.66	5.20	4.85

C3 Effect of harvester's forward speed and stripper rotor speed on lodging loss at two levels of rotor height

Lodging loss (percent of total yield)

	R_1 (270mm)						R_2 (220mm)					
	Rep. 1	Rep. 2	Rep. 3	Mean			Rep. 1	Rep. 2	Rep. 3	Mean		
				UV	U	V				UV	U	V
U_1V_1	0.00	1.20	1.03	0.74			2.56	2.72	2.30	2.53		
U_1V_2	1.06	3.81	1.19	2.02			1.93	5.17	2.94	3.35		
U_1V_3	3.07	0.63	2.46	2.05			2.68	2.07	2.89	2.55		
U_1V_4	0.95	1.49	4.35	2.26	U_1	V_1	3.54	2.56	3.09	3.06	U_1	V_1
U_1V_5	4.49	3.74	1.72	3.32	2.08	2.71	2.15	0.00	2.18	1.44	2.59	3.05
U_2V_1	1.11	2.74	4.50	2.78			3.14	3.28	2.81	3.08		
U_2V_2	2.88	3.38	2.08	2.78			2.87	2.42	3.47	2.92		
U_2V_3	2.08	1.39	0.74	1.40			3.51	3.26	3.16	3.31		
U_2V_4	2.60	2.64	2.52	2.59	U_2	V_2	1.73	2.80	2.74	2.42	U_2	V_2
U_2V_5	2.18	2.98	5.71	3.62	2.63	2.66	2.59	2.44	2.21	2.41	2.83	3.03
U_3V_1	4.17	0.81	0.59	1.86			1.49	1.51	2.18	1.73		
U_3V_2	1.89	1.75	1.58	1.74			3.03	2.65	2.65	2.78		

U_3V_3	2.55	2.34	4.65	3.18			3.79	2.07	2.60	2.82		
U_3V_4	1.03	5.55	4.79	3.79	U_3	V_3	2.29	4.68	3.97	3.65	U_3	V_3
U_3V_5	5.94	1.76	3.82	3.84	2.88	2.26	3.27	3.72	4.77	3.92	2.98	2.82
U_4V_1	5.22	6.02	2.80	4.68			3.02	5.70	3.30	4.00		
U_4V_2	1.48	4.81	3.95	3.41			4.66	1.86	2.63	3.05		
U_4V_3	2.52	2.31	4.10	2.98			2.91	4.14	3.65	3.57		
U_4V_4	4.19	1.24	2.21	2.55	U_4	V_4	2.14	2.23	5.21	3.19	U_4	V_4
U_4V_5	3.42	3.04	3.91	3.46	3.42	3.45	3.20	4.42	0.00	2.54	3.27	2.86
U_5V_1	3.03	4.80	2.70	3.51			1.41	5.92	4.33	3.89		
U_5V_2	4.35	3.00	2.64	3.33			4.91	0.00	4.31	3.07		
U_5V_3	2.89	0.80	1.33	1.67			0.63	3.23	1.72	1.86		
U_5V_4	9.81	5.03	3.37	6.07	U_5	V_5	3.70	2.18	0.00	1.96	U_5	V_5
U_5V_5	2.25	3.33	3.86	3.15	3.55	3.48	3.22	3.65	7.97	4.95	3.15	3.05

C4 Effect of harvester's forward speed and stripper rotor speed on total loss at two levels of rotor height

Total loss (percent of total yield)

	R_1 (270mm)						R_2 (220mm)					
	Rep. 1	Rep. 2	Rep. 3	Mean			Rep. 1	Rep. 2	Rep. 3	Mean		
				UV	U	V				UV	U	V
U_1V_1	10.65	9.60	7.60	9.28			16.85	20.80	12.64	16.76		
U_1V_2	14.50	16.55	12.87	14.64			8.75	23.08	8.96	13.60		
U_1V_3	21.98	9.28	11.04	14.10			12.02	9.11	20.56	13.90		
U_1V_4	13.40	9.01	12.43	11.61	U_1	V_1	17.21	19.62	19.50	18.78	U_1	V_1
U_1V_5	13.22	10.79	8.71	10.94	12.11	14.71	13.62	8.79	18.44	13.62	15.33	15.11
U_2V_1	11.46	14.56	14.88	13.63			12.96	18.81	7.94	13.24		
U_2V_2	14.42	14.31	15.23	14.65			14.08	19.00	10.19	14.42		
U_2V_3	14.71	6.10	3.83	8.21			15.69	24.91	9.87	16.82		
U_2V_4	9.97	14.14	15.81	13.31	U_2	V_2	12.74	9.73	22.42	14.96	U_2	V_2
U_2V_5	9.65	15.27	14.41	13.11	12.58	14.07	22.91	22.80	10.28	18.66	15.62	15.81
U_3V_1	13.95	14.81	10.02	12.93			11.19	12.36	14.47	12.67		
U_3V_2	13.03	10.40	14.21	12.55			14.78	20.14	11.33	15.42		

U_3V_3	12.86	9.98	14.80	12.55			12.68	18.83	14.22	15.24			
U_3V_4	9.93	16.44	17.02	14.46	U_3	V_3	18.98	11.82	14.19	15.00	U_3	V_3	
U_3V_5	18.96	8.20	14.13	13.76	13.25	11.70	10.68	26.87	26.29	21.28	15.92	15.00	
U_4V_1	21.92	16.95	8.23	15.70			16.17	15.46	14.83	15.49			
U_4V_2	14.66	14.25	16.38	15.10			12.69	13.30	15.32	13.77			
U_4V_3	14.52	10.23	15.93	13.56			21.51	21.02	13.75	18.78			
U_4V_4	12.74	12.85	10.65	12.08	U_4	V_4	14.81	16.13	18.07	16.34	U_4	V_4	
U_4V_5	18.06	16.23	15.78	16.69	14.26	13.32	17.53	20.63	8.65	15.60	16.00	15.05	
U_5V_1	17.14	20.96	27.97	22.02			12.19	21.74	18.20	17.38			
U_5V_2	14.99	10.81	14.47	13.42			23.09	17.72	24.74	21.85			
U_5V_3	15.04	8.55	6.660	10.06			11.72	12.31	6.74	10.26			
U_5V_4	18.59	15.92	10.92	15.14	U_5	V_5	10.68	5.35	14.50	10.18	U_5	V_5	
U_5V_5	17.33	11.49	12.22	13.68	14.86	13.64	12.17	17.35	21.54	17.02	15.34	17.24	

C5 Effect of harvester's forward speed and stripper rotor on speed time taken loss at two levels of rotor height

	Time taken (seconds)											
	R_1 (270mm)						R_2 (220mm)					
	Rep. 1	Rep. 2	Rep. 3	Mean			Rep. 1	Rep. 2	Rep. 3	Mean		
				UV	U	V				UV	U	V
U_1V_1	13	10	13	12			14	10	15	13		
U_1V_2	21	13	14	16			18	14	16	16		
U_1V_3	20	19	16	18			15	13	16	15		
U_1V_4	14	9	14	12	U_1	V_1	12	15	13	13	U_1	V_1
U_1V_5	17	15	12	15	15	14	20	15	18	18	15	13.6
U_2V_1	15	18	13	15			17	12	14	14		
U_2V_2	12	21	15	16			11	8	10	10		
U_2V_3	19	10	12	14			14	17	13	15		
U_2V_4	10	10	18	13	U_2	V_2	13	12	9	11	U_2	V_2
U_2V_5	12	12	11	12	14	15	13	18	9	13	13	14
U_3V_1	15	15	19	16			17	12	17	15		
U_3V_2	18	10	12	13			15	17	12	15		

U_3V_3	18	16	13	16			20	17	16	18				
U_3V_4	21	18	16	18	U_3	V_3	20	16	18	18	U_3	V_3		
U_3V_5	17	20	20	19	17	14	18	16	16	17	17	15		
U_4V_1	13	14	8	12			16	11	10	12				
U_4V_2	15	12	12	13			17	10	13	13				
U_4V_3	15	8	7	10			12	17	13	14				
U_4V_4	16	11	12	13	U_4	V_4	11	10	10	10	U_4	V_4		
U_4V_5	15	17	11	14	13	14	13	7	9	10	12	14.6		
U_5V_1	13	17	16	15			18	12	13	14				
U_5V_2	15	20	12	16			14	17	18	16				
U_5V_3	15	11	6	11			18	15	14	16				
U_5V_4	18	16	13	16	U_5	V_5	17	18	12	16	U_5	V_5		
U_5V_5	18	16	13	16	15	15	12	13	10	12	15	14		

C6 Effect of harvester's forward speed and stripper rotor speed on fuel consumed at two levels of rotor height

Fuel consumed (milliliters)

	R_1 (270mm)						R_2 (220mm)					
	Rep. 1	Rep. 2	Rep. 3	Mean			Rep. 1	Rep. 2	Rep. 3	Mean		
				UV	U	V				UV	U	V
U_1V_1	7.8	6.0	7.8	7.2			8.4	6.0	9.0	7.8		
U_1V_2	12.6	7.8	8.4	9.6			10.8	8.4	9.6	9.6		
U_1V_3	12.0	11.4	9.6	11.0			9.0	7.8	9.6	8.8		
U_1V_4	8.4	5.4	8.4	7.4	U_1	V_1	7.2	9.0	7.8	8.0	U_1	V_1
U_1V_5	10.2	9.0	7.2	8.8	8.8	8.5	12.0	9.0	10.8	10.6	9.0	8.3
U_2V_1	9.0	10.8	7.8	9.2			10.2	7.2	8.4	8.6		
U_2V_2	7.2	12.6	9.0	9.6			6.6	5.0	8.0	5.9		
U_2V_3	11.4	6.0	7.2	8.2			8.4	10.2	7.8	8.8		
U_2V_4	6.0	6.0	10.8	7.6	U_2	V_2	7.8	7.2	5.4	6.8	U_2	V_2
U_2V_5	7.2	7.2	6.6	7.0	8.3	8.9	7.8	10.8	5.4	8.0	7.6	8.4
U_3V_1	9.0	9.0	11.4	9.8			10.2	7.2	10.2	9.2		
U_3V_2	10.8	6.0	7.2	8.0			9.0	10.2	7.2	8.8		

U_3V_3	10.8	9.6	7.8	9.4			12.0	10.2	9.6	10.6		
U_3V_4	12.6	10.8	9.6	11.0	U_3	V_3	12.0	9.6	10.8	10.8	U_3	V_3
U_3V_5	10.2	12.0	12.0	11.4	9.9	8.5	10.8	9.6	9.6	10.0	9.9	9.2
U_4V_1	7.8	8.4	4.8	7.0			9.6	6.6	6.0	7.4		
U_4V_2	9.0	7.2	7.2	7.8			10.2	6.0	7.8	8.0		
U_4V_3	9.0	4.8	4.2	6.0			7.2	10.2	7.8	8.4		
U_4V_4	9.6	6.6	7.2	7.8	U_4	V_4	6.6	6.0	6.0	6.2	U_4	V_4
U_4V_5	9.0	10.2	6.6	8.6	7.4	8.6	7.8	4.2	5.4	5.8	7.2	8.2
U_5V_1	7.8	10.2	9.6	9.2			10.8	7.2	7.8	8.6		
U_5V_2	9.0	12.0	7.2	9.4			8.4	10.2	10.8	9.8		
U_5V_3	9.0	6.6	4.0	7.9			10.8	9.0	8.4	9.4		
U_5V_4	10.8	9.6	7.8	9.4	U_5	V_5	10.2	10.8	7.2	9.4	U_5	V_5
U_5V_5	10.8	9.6	7.8	9.4	9.1	9.0	7.2	7.8	6.0	7.0	8.8	8.3

C7 Effect of harvester's forward speed and stripper rotor speed on grain purity at two levels of rotor height

	Grain purity (percent of total yield)											
	R_1 (270mm)						R_2 (220mm)					
	Rep. 1	Rep. 2	Rep. 3	Mean			Rep. 1	Rep. 2	Rep. 3	Mean		
				UV	U	V				UV	U	V
U_1V_1	87.96	83.61	92.33	87.97			86.83	90.55	92.76	90.05		
U_1V_2	89.15	89.46	96.85	91.82			91.78	90.56	91.31	91.22		
U_1V_3	83.85	94.63	90.79	89.76			93.52	91.44	91.57	92.18		
U_1V_4	85.79	87.43	91.45	88.22	U_1	V_1	84.25	86.86	93.13	88.08	U_1	V_1
U_1V_5	91.91	90.43	88.71	90.35	89.62	89.42	96.46	84.09	93.03	91.19	90.54	89.4
U_2V_1	93.56	85.38	85.92	88.29			87.76	93.19	85.04	88.66		
U_2V_2	92.86	92.97	93.65	93.16			84.06	91.91	88.21	87.82		
U_2V_3	87.80	88.32	91.23	89.12			86.29	90.03	97.84	91.39		
U_2V_4	87.09	91.90	93.68	90.89	U_2	V_2	90.11	90.70	93.25	91.35	U_2	V_2
U_2V_5	87.34	87.61	86.88	87.28	89.75	90.54	74.43	92.41	84.74	83.86	88.62	89.9
U_3V_1	85.90	94.31	95.61	91.94			97.61	87.36	92.31	92.43		
U_3V_2	88.35	94.06	89.36	90.59			91.28	85.78	89.95	89.00		

U_3V_3	90.47	91.19	94.87	92.18			89.40	88.69	90.92	89.67				
U_3V_4	83.67	86.89	89.53	86.70	U_3	V_3	80.14	91.60	93.79	88.51	U_3	V_3		
U_3V_5	87.57	92.12	93.59	91.09	90.50	90.67	93.44	90.34	89.77	91.18	90.16	91.1		
U_4V_1	83.42	88.15	93.10	88.22			86.52	82.28	93.08	87.29				
U_4V_2	88.16	87.88	91.64	89.23			96.95	90.61	90.23	92.60				
U_4V_3	90.51	82.63	91.31	88.15			86.04	90.17	92.53	89.58				
U_4V_4	84.84	91.76	93.48	90.03	U_4	V_4	95.60	76.94	90.27	87.60	U_4	V_4		
U_4V_5	83.35	94.44	89.46	89.08	88.94	88.47	92.14	91.14	94.24	92.51	89.92	89.2		
U_5V_1	90.60	91.65	89.84	90.70			91.44	84.00	87.48	87.64				
U_5V_2	85.79	88.32	89.61	87.91			91.59	91.74	82.25	88.69				
U_5V_3	97.06	93.38	91.96	94.13			93.12	89.93	95.22	92.76				
U_5V_4	91.95	78.13	89.38	86.49	U_5	V_5	87.76	94.60	88.50	90.29	U_5	V_5		
U_5V_5	82.62	96.97	93.05	90.88	90.02	89.74	86.23	87.72	87.34	87.10	89.30	89.2		

C8 Effect of harvester's forward speed and stripper rotor speed on harvester efficiency at two levels of rotor height

Harvester efficiency (percent of total grain stripped total yield)

	R_1 (270mm)						R_2 (220mm)					
	Rep. 1	Rep. 2	Rep. 3	Mean			Rep. 1	Rep. 2	Rep. 3	Mean		
				UV	U	V				UV	U	V
U_1V_1	84.78	86.29	89.15	86.74			75.93	71.35	81.94	76.41		
U_1V_2	79.29	76.36	81.61	79.09			87.50	67.03	87.20	80.58		
U_1V_3	68.60	86.75	84.23	79.86			82.83	86.98	70.63	80.15		
U_1V_4	80.86	87.13	82.25	83.41	U_1	V_1	75.41	71.97	72.15	73.18	U_1	V_1
U_1V_5	80.97	84.57	87.56	84.37	82.69	78.6	80.54	87.45	73.66	80.55	78.17	78.0
U_2V_1	83.63	73.20	78.74	78.52			81.49	73.13	88.66	81.09		
U_2V_2	77.40	77.56	78.24	77.52			77.02	72.86	85.44	78.44		
U_2V_3	76.98	91.28	94.53	87.60			71.59	64.42	85.90	73.97		
U_2V_4	85.76	79.80	69.41	78.32	U_2	V_2	81.80	86.10	67.97	78.62	U_2	V_2
U_2V_5	86.21	72.18	70.41	76.27	79.69	79.2	46.15	64.57	85.32	65.35	75.49	76.0
U_3V_1	80.10	78.84	85.68	81.54			84.02	82.34	79.33	81.90		
U_3V_2	81.38	85.15	79.70	82.08			78.89	71.23	83.81	77.98		

U_3V_3	81.63	85.75	78.86	82.08			81.88	73.10	79.69	78.22		
U_3V_4	85.81	76.52	75.69	79.34	U_3	V_3	72.88	83.11	79.73	78.57	U_3	V_3
U_3V_5	71.81	88.29	79.81	80.00	81.01	82.5	84.74	61.62	62.45	69.60	77.25	77.1
U_4V_1	68.68	75.79	88.24	77.57			72.90	73.91	78.82	75.21		
U_4V_2	79.06	73.65	76.60	76.44			67.58	76.72	78.12	74.14		
U_4V_3	69.26	85.39	77.26	77.30			59.18	63.97	80.36	67.84		
U_4V_4	74.66	74.50	84.78	77.98	U_4	V_4	78.84	76.96	64.19	73.33	U_4	V_4
U_4V_5	74.20	66.81	77.46	72.82	76.42	78.7	74.96	60.53	87.64	74.38	72.98	77.8
U_5V_1	75.51	70.01	60.05	68.52			82.58	68.95	74..03	75.19		
U_5V_2	78.59	84.56	79.33	80.83			67.01	74.69	64.66	68.79		
U_5V_3	78.52	87.79	90.57	85.63			83.26	82.42	90.37	85.35		
U_5V_4	66.30	72.97	84.40	74.56	U_5	V_5	84.75	92.36	79.29	85.47	U_5	V_5
U_5V_5	75.24	83.59	82.54	80.46	78	78.8	82.61	75.22	69.23	75.69	78.10	73.1

C9 Effect of harvester's forward speed and stripper rotor speed on field efficiency at two levels of rotor height

Harvester field efficiency (percent of harvesting time / total time)

	R_1 (270mm)						R_2 (220mm)					
	Rep. 1	Rep. 2	Rep. 3	Mean			Rep. 1	Rep. 2	Rep. 3	Mean		
				UV	U	V				UV	U	V
U_1V_1	61.9	45.5	59.1	55.5			45.2	43.5	71.4	53.4		
U_1V_2	67.7	59.1	58.3	61.7			62.1	58.3	66.7	62.4		
U_1V_3	66.7	50.0	69.6	62.1			50.0	61.9	61.5	57.8		
U_1V_4	51.9	47.4	63.6	54.3	U_1	V_1	40.0	46.9	61.9	49.6	U_1	V_1
U_1V_5	43.6	71.4	60.0	58.3	58.4	57.4	60.6	68.2	64.3	64.4	57.5	54.8
U_2V_1	53.6	56.3	65.0	58.3			68.0	57.1	66.7	63.9		
U_2V_2	44.4	52.5	62.5	53.1			50.0	40.0	50.0	46.7		
U_2V_3	70.4	58.8	63.2	64.1			41.2	63.0	61.9	55.4		
U_2V_4	52.6	55.6	66.7	58.3	U_2	V_2	56.5	60.0	56.3	57.6	U_2	V_2
U_2V_5	42.9	50.0	47.8	46.9	56.1	55.6	46.4	58.1	52.9	52.5	55.2	56.5
U_3V_1	68.2	46.9	59.4	58.2			45.9	37.5	58.6	47.3		
U_3V_2	62.1	55.6	57.1	58.3			65.2	53.1	52.2	56.8		
U_3V_3	69.2	57.1	59.1	61.8			71.4	63.0	61.5	65.3		

U_3V_4	70.0	60.0	66.7	65.6	U_3	V_3	57.1	61.5	62.1	60.2	U_3	V_3
U_3V_5	68.0	69.0	66.7	67.9	62.4	57.9	66.7	64.0	55.2	62.0	58.3	57.7
U_4V_1	54.2	53.8	53.3	53.8			44.4	52.4	58.8	51.9		
U_4V_2	39.5	41.4	54.5	45.1			63.0	28.6	61.9	51.2		
U_4V_3	50.0	53.3	46.7	50.0			54.5	51.5	61.9	55.0		
U_4V_4	55.2	35.5	50.0	46.9	U_4	V_4	52.4	50.0	55.6	52.7	U_4	V_4
U_4V_5	65.2	68.0	61.1	64.8	52.1	56.32	65.0	21.2	64.3	50.2	52.4	56.4
U_5V_1	56.5	63.0	64.0	61.2			66.7	44.4	61.9	57.7		
U_5V_2	53.6	69.0	57.1	59.9			58.3	73.9	64.3	65.5		
U_5V_3	68.2	45.8	40.0	51.3			48.6	50.0	63.6	54.1		
U_5V_4	51.4	61.5	56.5	56.5	U_5	V_5	53.1	69.2	63.2	61.8	U_5	V_5
U_5V_5	60.0	66.7	56.5	61.1	58.0	59.8	40.0	65.0	52.6	52.5	58.3	56.3

Appendix D1: The 2 x 5 x 5 factorial treatment combinations of rotor height (R), harvester forward speed (U) and rotor speed (V).

Treatments

$R_1U_1V_1$	$R_1U_1V_2$	$R_1U_1V_3$	$R_1U_1V_4$	$R_1U_1V_5$
$R_1U_2V_1$	$R_1U_2V_2$	$R_1U_2V_3$	$R_1U_2V_4$	$R_1U_2V_5$
$R_1U_3V_1$	$R_1U_3V_2$	$R_1U_3V_3$	$R_1U_3V_4$	$R_1U_3V_5$
$R_1U_4V_1$	$R_1U_4V_2$	$R_1U_4V_3$	$R_1U_4V_4$	$R_1U_4V_5$
$R_1U_5V_1$	$R_1U_5V_2$	$R_1U_5V_3$	$R_1U_5V_4$	$R_1U_5V_5$
$R_2U_1V_1$	$R_2U_1V_2$	$R_2U_1V_3$	$R_2U_1V_4$	$R_2U_1V_5$
$R_2U_2V_1$	$R_2U_2V_2$	$R_2U_2V_3$	$R_2U_2V_4$	$R_2U_2V_5$
$R_2U_3V_1$	$R_2U_3V_2$	$R_2U_3V_3$	$R_2U_3V_4$	$R_2U_3V_5$
$R_2U_4V_1$	$R_2U_4V_2$	$R_2U_4V_3$	$R_2U_4V_4$	$R_2U_4V_5$
$R_2U_5V_1$	$R_2U_5V_2$	$R_2U_5V_3$	$R_2U_5V_4$	$R_2U_5V_5$

Appendix D2: Layout of the 2x5x5 factorial experiment in a randomized complete block design

Block 1

$R_2U_1V_4$	$R_2U_1V_4$	$R_1U_1V_1$	$R_1U_1V_4$	$R_2U_3V_2$	$R_1U_4V_5$	$R_2U_1V_2$	$R_1U_3V_5$	$R_1U_5V_1$	$R_2U_4V_4$
$R_2U_2V_3$	$R_2U_4V_3$	$R_2U_4V_5$	$R_1U_2V_5$	$R_1U_2V_4$	$R_2U_3V_4$	$R_1U_1V_2$	$R_1U_4V_4$	$R_2U_1V_5$	$R_2U_3V_5$
$R_1U_1V_5$	$R_2U_2V_2$	$R_1U_4V_3$	$R_2U_5V_4$	$R_2U_5V_1$	$R_1U_5V_4$	$R_1U_5V_2$	$R_2U_5V_2$	$R_2U_5V_5$	$R_2U_2V_1$
$R_2U_4V_1$	$R_1U_2V_2$	$R_2U_5V_3$	$R_2U_5V_3$	$R_2U_3V_3$	$R_1U_3V_1$	$R_1U_3V_2$	$R_1U_1V_3$	$R_2U_3V_1$	$R_2U_4V_2$
$R_1U_4V_2$	$R_1U_2V_1$	$R_1U_5V_5$	$R_2U_1V_3$	$R_1U_2V_4$	$R_1U_2V_3$	$R_1U_3V_3$	$R_1U_4V_1$	$R_2U_2V_4$	$R_1U_5V_3$

Block 2

$R_2U_4V_2$	$R_2U_4V_2$	$R_1U_5V_1$	$R_1U_3V_1$	$R_2U_3V_3$	$R_1U_2V_2$	$R_1U_4V_1$	$R_2U_4V_4$	$R_1U_1V_2$	$R_2U_2V_5$
$R_2U_4V_5$	$R_2U_1V_1$	$R_2U_1V_4$	$R_2U_3V_1$	$R_1U_4V_4$	$R_1U_2V_1$	$R_1U_5V_4$	$R_2U_3V_5$	$R_1U_3V_5$	$R_2U_2V_4$
$R_2U_2V_2$	$R_2U_5V_1$	$R_2U_4V_3$	$R_1U_1V_3$	$R_2U_2V_5$	$R_2U_2V_3$	$R_2U_1V_2$	$R_2U_5V_4$	$R_1U_3V_4$	$R_1U_2V_4$
$R_1U_1V_4$	$R_2U_4V_1$	$R_1U_5V_5$	$R_1U_5V_3$	$R_2U_5V_3$	$R_1U_3V_3$	$R_1U_4V_5$	$R_1U_4V_3$	$R_2U_1V_5$	$R_2U_2V_1$
$R_1U_3V_2$	$R_2U_2V_4$	$R_2U_5V_2$	$R_1U_1V_1$	$R_1U_5V_2$	$R_2U_3V_2$	$R_2U_1V_3$	$R_1U_1V_5$	$R_1U_2V_3$	$R_2U_5V_5$

Block 3

$R_2U_5V_2$	$R_2U_3V_2$	$R_2U_4V_1$	$R_2U_5V_4$	$R_2U_1V_4$	$R_1U_3V_5$	$R_1U_1V_3$	$R_2U_2V_2$	$R_2U_5V_3$	$R_1U_1V_4$
$R_1U_5V_1$	$R_2U_5V_1$	$R_2U_3V_5$	$R_2U_1V_1$	$R_1U_3V_1$	$R_1U_2V_2$	$R_2U_5V_5$	$R_2U_2V_3$	$R_2U_1V_2$	$R_1U_1V_5$
$R_2U_2V_1$	$R_2U_1V_5$	$R_1U_3V_4$	$R_1U_3V_3$	$R_1U_1V_1$	$R_2U_4V_2$	$R_2U_4V_4$	$R_2U_2V_4$	$R_1U_4V_4$	$R_1U_5V_4$
$R_1U_2V_4$	$R_1U_4V_2$	$R_2U_3V_1$	$R_1U_1V_2$	$R_1U_4V_5$	$R_1U_5V_5$	$R_1U_2V_5$	$R_2U_2V_5$	$R_2U_3V_3$	$R_1U_3V_2$
$R_2U_4V_3$	$R_1U_5V_2$	$R_2U_1V_3$	$R_2U_4V_5$	$R_1U_2V_3$	$R_1U_4V_1$	$R_2U_3V_4$	$R_1U_2V_1$	$R_1U_4V_3$	$R_1U_5V_3$