DEVELOPMENT AND PERFORMANCE EVALUATION OF AN IMPROVED SOYBEAN THRESHER

BY

AMADU NOMAU
M.SC/ENG/49390/2005-2006

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL,
AHMADU BELLO UNIVERSITY, ZARIA NIGERIA

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER IN SCIENCE DEGREE IN AGRICULTURAL ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING.
AHMADU BELLO UNIVERSITY, ZARIA NIGERIA.

FEBRUARY,2012

DECLARATION

I, Amadu Nomau hereby declare that this thesis has been entirely written by me. It is a product of my research work and has never been presented, accepted or defended anywhere for the award of a higher degree. All the sources of information which are not my own originals were duly acknowledged by means of references.

.

AMADU NOMAU

DATE--

CERTIFICATION

This thesis titled DEVELOPMENT AND PERFORMANCE EVALUATION OF AN IMPROVED SOYBEAN THRESHER by AMADU NOMAU, meets the requirements governing the award of Master of Science degree in Agricultural Engineering of Ahmadu Bello University, and is approved for its contribution to scientific knowledge and literary presentation.

-- -----------------------

Dr. U.S Mohammed Date
Chairman supervisory committee

-- -----------------------

Prof. A.M.I EL-Okene Date
Member, supervisory committee

-- -----------------------

Prof. D.D Yusuf Date
Head of Department
Agricultural Engineering.

-- -----------------------

Prof. J.A Adebayo Date
Dean, postgraduate school
Ahmadu Bello University, Zaria

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to the almighty God for his permission without which nothing would have been possible.

My profound gratitude goes to my major supervisor, Dr. U.S Mohammed whose moral support, patience and diligence enabled me to complete this work. All the necessary corrections he has given to me have made this work a success. My appreciation is also due to my co-supervisor, Prof. A.M.I El-Okene for his contribution throughout this work. I also thank all the workshop staff who assisted me in one way or the other during the fabrication of the soybean prototype machine, specifically Mr. Andrew Bako and Mal. Yusuf Babale. I also acknowledge the assistance of my office mate Mr. T. Yusuf who was also my course mate at this postgraduate level. Finally, my profound gratitude goes to my family, my wife Dorcas and my little boy Emmanuel (Aboy).May God bless you all.

DEDICATION

This work is dedicated to my late mother, Mrs. Turai K. Nomau and to my wife and little son Emmanuel for their patience while conducting this M.Sc. Programme.

ABSTRACT

Due to the bulky nature of the soybean and since it has to be harvested with the stems, the conventional threshers for maize and guinea corn cannot be used for the crop without modifications. An improved soybean thresher has been developed and its performance evaluation has also been carried out. From the results, threshing efficiency, cleaning efficiency, mechanical grain damage, scatter loss and throughput capacity of 99%, 95%, 1.01%, 2.7% and 25.5kg/hr were obtained respectively. Also from the ANOVA statistical analysis carried out, it shows that all the in-dependable variables i.e. feed rate, moisture content and speed have a significant effects on the dependable variables i.e. Threshing efficiency, cleaning efficiency, scatter loss, mechanical grain damage and throughput capacity. A comparison between the performance of the improved soybean thresher and the old IAR soybean thresher was carried out and it reveals that the difference between the cleaning efficiency of the new thresher and that of the old thresher is significant at 1% probability level. It also shows that the difference in the threshing efficiency of the new thresher with the old one is significant at 5% probability level. This means that there is an improvement in the performance of the old I.A.R soybean thresher by the improved one.

TABLE OF CONTENTS

CONTENTS PAGE

CHAPTER FIVE

List of Figures

List of Tables

List of Appendices

List of Plates

CHAPTER

1.0 INTRODUCTION

Soybean *(Glycine max (L) men),* is a herbaceous annual legume that is usually erect, bushy and rather leafy. Cultivars range from 45-120 cm in height with growth period of 75-150 days and mostly have a main stem that branches from the lower nodes (Smith and Huyser, 1987).The extend of branching depends on environmental conditions (light and available moisture). The stems, leaves and pods are covered with fine towny or grey pubescence. The pods are small, straight or slightly curved and range in colour from light straw to nearly black. The pods contain one or four seeds round to elliptical in shape. Popular commercial cultivars have straw yellow seeds, but cultivars with greenish yellow, brown or black seeds are also found. Soybean is one of the world's most important food crops having superior amino acid profile compared to other sources of plant protein. It provide about 64 percent of the world's oil seed meal supply and is a major source of oil, accounting for about 29 percent of total world production (Smith and Huyser, 1987). It contains about 40-41% protein and 20.5-21.5 % oil. Soybean is processed to separate the oil from the protein meal which is incorporated into the animal and poultry feeds. It is known to have been grown in China and Japan for thousands of years. It is referred to the "meat of the world" because it is the cheapest source of protein and oil. Soybean combines in one corm both the dominant world supply of edible vegetable oil, and the dominant supply of high-protein feed supplements for livestock. Soybean seeds have a wider range of economic importance. It ranges from industrial, food, pharmaceutical and agricultural products (Smith and Huyser, 1987). Worldwide soybean production amounts to around 130 million tonnes per year utilizing around 60 million hectares.(F.A.O, 1980). If processed and used domestically soybean could become as economically attractive in Nigeria as in other parts of the world. Soybean can be the most practical means of relief from kwashiorkor (protein-calorie malnutrition) which is on the increasing prevalence among young African children. Other means of protein like wild animals and fish have disappeared due to indiscriminate hunting and fishing and has become very expensive for an average African family, hence the introduction of soybean crop in west and central African countries being encouraging (Ayagi, 1994). It can also be processed into a wide range of products for human consumption and utilization, which include oil for making margarine, as cooking oil, salad oils, synthetic gums, soaps and paints. It is also used in making soy flour used for bread, biscuits etc. Whole seeds can be soaked overnight and cooked as bean or for dawadawa (a Northern Nigerian food sweating spice). Other products are soybean milk, soy-source, soybean curd and bean spouts (Marina, 1991). Soybeans are packed with important nutrients including calcium, magnesium and many B-complex vitamins.(Marina, 1991). From investigations it has shown that from 100 g of soymilk, you can get 2.8-3.4 g of protein, 1.5 g lipids, 12-24 mg of calcium, 36-49 mg phosphorus, 50 mg potassium, 15 mg of sodium, 0.02-0.05 mg iron (Marina, 1991). It is also comparable to cow milk for amino acids and vitamin B. In view of this several African countries are embarking upon the commercial production of soymilk as a substitute for cow milk (Marina, 1991). Soybean production represent an important source of foreign currency especially in countries like Brazil and Argentina (Duque,1999). In Argentina more than 50 percent of the export currency is generated from soybean complex, while in Brazil the soybean complex generates yearly US $24.5 billion in income and earning about US $ 5.7 billion in foreign exchange (Duque, 1999). In some developing countries such as Nigeria, especially in the rural areas soybean represent the best protein source available for improving the nutritional value of traditional food. The crop has revolutionized the rural economy by raising the living standard of soybean farmers, especially the women and children.

Table 1; Estimated soybean production in major producing countries and regions as at 1980.

S/N	Country Region	Total Land Area (1,000 ha)	Production (1,000 MT)	Yield Kg/ha
1	World	52,639	83,481	1,586
2	N/C America	57,929	50,468	1,809
3	U. S. A	27,460	49,454	1,801
4	South America	11,256	19,552	1,737
5	Brazil	8,766	15,153	1,728
6	Asia	11,662	11,964	1,026
7	Africa	327	310	946
8	China	9621 F	10,0267	1,046
9	Nigeria	197 F	77 F	388

Source :(F.A.O. 1980)

In Nigeria, improvement in production of soybean can only be possible when relevant machinery and equipments are developed for post harvest processing to encourage small-scale farmers (Ayagi, 1994).

Soybean is a warm season crop and its climatic requirements are about the same as those of maize. For germination and early plant development there is the need for a moderate moisture supply. The period of germination is the most critical stage and an excess or deficiency of soil moisture at this time could be harmful. Soil temperature of 15^{o}C or more favour rapid germination and vigorous seedling growth which is essential for successful competition with weeds. Growing temperature of 20^{o}C to 25^{o}C appear to be optimum. Soybean produced in higher temperatures (about 32^{o}C) tend to be low in oil quantity and quality (Marina, 1991). Soybean plants are very sensitive to light duration (photo-period) they are short day plants. Soybean can be grown on a wide range of soil types, but thrive best on sandy or dry loams and alluvial soils of good fertility. The optimum soil PH ranges from 6.0-6.5(Marina, 1991).

1.1 Cultivation, Harvesting and Threshing

Land preparation for soybean is similar to that for maize, the land is ploughed and harrowed. Seeds are sown at a seed rate of 50-75 kg/ha depending on the plant population required (Hoki and Esmay,1979). The sowing depth for soybeans ranges from 2.5-5.0 cm.

When soybeans are grown for seed, harvesting is done before the pods shatter. The best stage is when the pods are fully mature with the seeds in the hand-dough state. The seeds should have moisture content of less than 15 %. In non-shattering cultivars, harvesting is delayed until the crop is fully dried.

The plants are either cut at ground level or pulled out of the ground. In the developed countries, most soybean crops are harvested with combines. They are dried for some days and then threshed. The seeds should be stored at a moisture content of 10-20% or less

1.1.1 Varieties of soybean.

Soybean is of so many varieties worldwide. Among the varieties found in the United States of America includes Amsay, Corsoy, Harosoy, Lee and Clark. All these varieties are of similar botanical characteristics and are adaptable to only the climatic conditions around the United States of America.

In 1984 due to lack of adaptable soybean varieties in Nigeria and also due to the poor agronomic attributes of the only popular variety "Malaya". In the limited era where it is adapted, the Nigerian scientist developed high yielding varieties through National Coordinated Research Project on Soybean. (NCRPS, 1988).

Among the varieties developed includes samsoy-I samsoy- 2, TGX 536-020, TGM 344, TGX 814-270, TGX 855-610.(NCRPS,1988). These varieties were found to be very adaptable in most of the northern states such as Kaduna, Kano, Niger, Plateau and Taraba (NCRPS,1988).

Table 2. Performance of some improved soybean varieties.

Variety	Yield (kg/ha)
TGX 849-2970	2,285
TGX 849-2940	1,883
TGX 539-5E	1,652
TGX 297-10F	1,824
Samsoy I	1,668
Samsoy II	1,689
Malaya	814
TGX 814-27D	1,892

(NCRPS, 1988)

1.2 Methods of Threshing Soybean

1.2.1 Manual threshing

After harvesting the crop is left on the field for curing. In a number of countries threshing is done by bamboo flails or by pulling a log of wood or stone roller over the crop or by large animal trampling or by sagging the crop and beating with clubs to thresh. Recently though, a number of threshers have been developed for the crop. However, the success of their uses is limited due to a high percentage of grain damage which is reported to be as high as 40 % .

1.2.2 Mechanical threshing:

A mechanical thresher has a threshing drum, which consist of a long cylindrical shaped member to which a series of pegs, knives or rasp bars are attached on its surface. The drum is mounted on two bearings and rotates in a perforated trough like member called the "concave". During threshing, the crop is fed between the threshing drum and the concave, where it is subjected to a high degree of impact and functional forces which detach the grains from the panicles (Amir, 1990).

Amir (1990) identified two types of mechanical threshers as the beater types and the axial flow type. According to him the beater thresher have a threshing cylinder which rotates in an enclosed chamber with lower part of the chamber forming the concave. The concave contain some perforations and there are no separate outlets in the machine for ejection of straw. The beating knives shred the straw into smaller pieces until it is small enough to pass with the grains through the small perforations in the concave for several complete turns. The repeated impact of the threshing pegs over a period of time threshes the crop and the grain is separated through the concave. Finally the straw is collected at a large straw outlet at the end of the concave. These types of threshers however cannot be used for threshing crops with tougher straw such as sorghum, soybean etc.

The axial flow type thresher is constructed with steel metal and is a general purpose thresher suitable for crops like paddy, wheat, sorghum, soybean and other grain crops. It has a capacity ranging from 300 kg/hr for wheat to 600 kg/hr for sorghum and a prime mover of about 5-7 hp (either petrol or diesel engine) (Amir, 1990). In the axial flow machines, crops moves spirally between the threshing drum and the circular concave for several complete turns.

1.3 Statement of the Problem.

One of the major problems encountered by the farmers in soybean production has been the method of threshing of the crop. Most harvesters in the country still operate at subsistence level. Over the years soybean threshing is accomplished by striking the grain with sticks or bamboo flails on the bare ground and through trampling by the hooves of Animals. This method is highly time consuming, energy demanding and drudgerious. The imported ones which the local farmers cannot afford to buy due to high cost and complexity in design which require skilful technical personnel. They also lack spare parts for maintenance. The locally developed ones have low capacity, and low threshing and cleaning efficiencies. It has been observed that considerable efforts have been made to develop a soybean thresher by different researchers; one of such threshers is the I.A.R. soybean thresher whose performance has not been satisfactory as reported by (Oforka, 2004). The I.A.R soybean thresher prototype is of smaller capacity with low performance efficiencies and high mechanical damage and scatter losses. The thresher has a low threshing efficiency of 80%, low cleaning efficiency of 70%, high mechanical grain damage of 2.0% and high scatter loss of 1.93 (Oforka, 2004).

1.4 Justification of the Study

The increase in demand for soybean meal and products makes it inevitable for efficient soybean threshing machine to be developed. This is because the traditional techniques of threshing soybean with sticks on bare floor results in a lot of grain damage and the occurrence of impurities like stones in the threshed bean resulting in poor quality product. The manual traditional method of threshing soybean is also high energy demanding, dradgerous and time consuming. This makes it necessary to develop a mechanical thresher for soybean and to ensure that the machine is affordable to the peasant farmers. The modification of the machine will give rise to improved efficiency and greater output during threshing.

1.5 Objective of the Study.

The broad objective of this study is to modify an existing I.A.R soybean thresher for improved efficiency and output.

With specific objectives of the study as follows:

1. To design and construct the thresher with modification of the threshing drum, the fan blades of the blower and the size of the hopper
2. To conduct performance evaluation of the thresher.
3. To compare the performance evaluation of the modified thresher with that of the old one

CHAPTER TWO

2.0 LITERATURE REVIEW.

2.1 Factors Affecting Threshing/Cleaning.

The threshing of soybean and other similar grain crops can be done with a squeezing action, a rubbing action or a combination of the two, and is a function of crop and machine variables. The crop variables are related to the type, variety, maturity and moisture content. The Thresher variables include type of cylinder and concave, cylinder tip speed and concave clearance (Sharma and Devnani, 1978).

More researchers have come up with different factors that affect threshing and cleaning of grains, which includes:

Cain and Holmes (1977) evaluated the impact damage to soybean seeds as a result of high speed collision with a steel plate and concluded that impact damage on seeds is dependent on both seed moisture content and velocity of impact.

Bartsch et al. (1979) reported that the threshing and conveying operations during harvesting consisted of dynamic events often involving a large momentum exchange during collisions of seeds with machine components and other seeds.

Paulsen E.T. (1978) stated that the common cause of damage in all grain handling studies is the particle velocity immediately before impact and

the rigidity of the surface against which the impact occurs. The percentage of splits increases as the impact velocity increases.

Hunt (1983) concluded that the moisture content at which threshing is carried out, concave drum clearance and pitch of screw are all factors that affects threshing.

Kepner et al. (1992) reported that four factors are very important when threshing is considered, These factor includes the peripheral speed of the cylinder, the clearance between cylinder and concave, crop maturity and the feed rate.

Foster (1967) stipulated that the presence of short straws create problems of sieve blockage and reduction of quality of final clean grains.

Hopsen (1969) postulated that the cleaning process presents more difficulties than the actual threshing process while Chouldhury and Kaul (1979) reported that winnowing time is 46.6 % higher than the threshing time. Mazvimavi,(1997), classified threshing and winnowing of any grain like soybean and sorghum which accounts for 50% of total labour used in the production as an arduous task.

Grains cleaning can be considered a stochastic process with particular changing orientation in a random manner both in time and space. The physical parameters affecting the cleaning process obtained from literature are broadly grouped into:

i) Machine factors, which are frequency of sieve oscillation, amplitude of oscillation, sieve slope, length of sieve, width of sieve, sieve hole diameter, threshing pressure, air density, angle of air dissection and terminal velocity (both grain and other materials).

ii) Crop factors, which include crop varieties, maturity stage, grain moisture content, straw moisture content, bulk density of grain, bulk density of straw, stalk length, grain diameter and angle of repose.

2.2 Mechanical and Physical Properties of Soybean

Huji (2002) conducted a research on the physical and mechanical properties of soybean using two varieties and reported as shown in table 3.

Table 3. Determination of some Physical and Mechanical Properties of Two Soybean Varieties.

	Samsoy – 2			TAS 1485 – ID		
Parameter & Limits	**No of Sample**	**Mean Value**	**Standard Deviation**	**No of Sample**	**Mean Value**	**Standard Deviation**
Length (mm)	60	6.39	0.47	60	6.47	0.64
Width (mm)	60	5.28	0.44	60	5.43	0.57
Thickness (mm)	60	4.69	0.51	60	4.65	0.65
Weight (g)	30	0.17	0.05	30	0.17	0.04
Surface Area (cm^2)	30	3.24	0.68	30	3.73	0.35
Volume (mm^3)	30	0.21	0.03	30	0.24	0.04
Density (kg/m^2)	30	0.83	0.43	30	0.21	0.05
Sphericity	30	1.44	0.33	30	1.65	0.41
Roundness	30	0.63	0.07	30	0.74	0.14
Angle of Repose	20	17.50	3.97	20	12.85	3.05
Grain to Formice	20	5.10	0.86	20	7.43	2.41
Hardness (kg)	20	28.06	6.57	20	19.37	4.77
Compressive Strength(N)	20	98.65	13.62	20	101.30	17.30

Source: (Huji, 2002)

From table 3 above, the standard of deviation for properties such as length, width, thickness, sphericity, roundness, angle of repose and compressive strength are higher for TAS 1485-ID which shows a wider deviation from the mean values compared to Samsoy-2.The coefficient of variation for properties such as volume, weight, density, hardness and surface area are higher for Samsoy-2 which also shows a higher variation within each parameters measured. (Huji, 2002)

2.3 Research and Development Efforts on Soybean Threshing.

Amir (1990) stated that one major improvement in threshing mechanism was the axial flow cylinder threshing system which when compared to the conventional transverse cylinder had higher capacity and lower seed damage.

Transverse threshing cylinders usually have high peripheral speeds. To maintain that speed when threshing entire soybean plants requires a considerable amount of energy. Kanafojski and Karwowski (1976) reported that soybean threshing cylinder required about 40 % of the engine's power. This is due to the fact that the threshing cylinder requires high power to thresh the whole soybean plant instead of only the pods. On the contrary, Mesquita and Hoag (1989) found out that soybean pods require only a small amount of energy to shatter them. To reduce mechanical damage while increasing the threshing capacity, efforts have been made to develop rotary threshing equipments. Amir (1990) reported higher capacity and lower damage to seeds with a twin rotor system than with a conventional transverse threshing cylinder.

Mesquite and Hanna (1993) studied the mechanics of soybean threshing by developing a test stand to analyse the mechanical actions of frictional rubbing and impact on soybean plants by stimulating the movement of experimental units over a row of soybean plants, thereby obtaining 93% and 92% threshing efficiencies respectively.

Reliability is achieved by simplification and improvement. Machines built with fewer parts have higher reliability and that improvement can be attained during the design phase or during the test phase by simplifying the design first and then improving it as required (Joshi, 1981).

According to Paulsen E.T.(1978), the goal of the threshing device must be to eliminate losses in the threshing process in terms of both macro and micro breaking, at the same time carrying out separation of the grains from the chaff.

2.4 Types of Mechanical Threshers.

Different types of mechanical threshers have been developed over the years by various researchers. Some of these threshers are as described below:

IIRI (1974) developed a thresher which has a full length flat oscillating conveyor tray installed directly under the concave. Threshed materials on the tray are then conveyed to a 60 x 60 perforated screen which removes the chaff and other impurities. A centrifugal blower is mounted above the oscillating tray to winnow the threshed grain. The whole oscillating tray is supported by a four bar linkage mounted on the base frame. The oscillating tray assembly replaces the auger, rotary cleaner and side collecting boards. This version of the axial flow thresher costs 15 % less to build than the original design.

Another type of mechanical thresher is the Bicol-type thresher which is found in the southern part of Luzon. The most popular type has a single drum a blower or separator. It is a flow through type with paddy fed through the top of the threshing drum. The material makes a three quarter turn before ejecting below the feed tray. Separation of the grain from the straw is done manually. It has the lowest separation efficiency because it has no separation system and because of the small concave area (Policarpo and Mcmennary, 1974).

The Kyowa type thresher was developed by the Japanese. It is a double drum thresher with a blower, but no separator. The two threshing drums are placed parallel to each other. The threshing drums can rotate at different speeds and can have different diameters. It is used for threshing paddy rice. Paddy is fed into the first drum and moves axially to the feed opening of the second drum. A centrifugal blower winnows the threshed grains as it falls from the concaves. The winnowed grain is conveyed out by an auger. It requires 8hp ship engine to operate (Policarpo and Mcmennary, 1974).

The Cotabato type thresher is also a flow through thresher that is widely used in the southern Philippine. It has two threshing drums, a blower and a separator. Paddy is fed along the whole width of the thresher's first drum. Final threshing occurs as the material goes to the second cylinder which runs faster than the first (Policarpo and Mcmennary, 1974).

In the central Luzon there is a popular type of thresher known as the Mccormick-Type thresher which is used in custom threshing operations.

It consists of a single threshing drum a blower, two oscillating screens and an auger. Paddy is fed to a floating belt conveyor which delivers materials to the top of a full-width peg tooth threshing drum. Grains falling from the concave are screened by the first oscillating sieve with air stream blowing out lighter impurities. Straw and other heavy impurities fall on another sieve for further separation. Cleaned grain is conveyed by an auger to the bagging section of the machine. An auxiliary auger delivers grain and tailings, blown by the air stream back to the threshing chamber for recycling (Policarpo and Mcmennary, 1974). The IRRI Potable thresher is a mechanical thresher that can be used for hold- on or throw-in threshing of paddy. It has a 30 cm diameter by 17 cm long peg tooth threshing drum. Woven wire mesh is used for the concave to increase the effective concave open area. It has a number of spiral louvers on the top cover. Light gauge angle iron and G.I sheets are used for the frame. The legs supporting the thresher fold to provide handles during transportation. The thresher is powered by a 5 hp gasoline engine. An automotive fan blade was attached directly to the engine output shaft to serve as a winnowing blower. A converging bell mouth shroud around the fan improves its air moving performance. The portable thresher is currently being adapted for threshing other crops like sorghum, soybean and peanuts (Policarpio and Mcmennamy ,1974).

2.5 Thresher Parameters.

Sharma and Devnani (1978) developed variable speed thresher used to determine threshing parameters like feed rate, grain output, threshing efficiency, energy consumption and grain damage for soybean and cowpea at the sun dried moisture content of 6.10 % and 6.5 % respectively and found that energy consumption in threshing was found to be directly proportional to the feed rate and cylinder tip speed, irrespective of the concave clearance. At the same rate of material flow and cylinder tip speed, the energy consumption for cowpea was higher than for soybean and the cleaning and separating units consumed 0.625 kW-hr /g for cowpea as against 0.50 kW-hr /g for soybeans.

This higher energy consumption at same speed and feed rate was associated with the more vegetative nature of the crop. It was also noted that the peripheral speed of the cylinder and concave clearance were the most important factors that cause grain damage. For the same cylinder speed and concave clearance, the visible soybean grain damage was greater for soybean whereas the internal grain damage was greater for the cowpea. It was also noticed that, although at higher speeds, the visible grain damage was below 5%, the internal damage to grain was very high as determined by germination test.

Singh (1969) designed a soybean thresher and observed that feed rate, concave clearance and type of concave have direct effect on the losses of grains with chaff. At cylinder speed of 2000 rpm concave clearance of 1.03 cm and at a moisture content of 9.5 % at feed rate of 1.15 kg/min, minimum seed damage was 3.6 % in the Swanson type thresher.

Rijpma et al. (1997) developed a soybean thresher separator in order to winnow the grain from the chaff. Vibration and separation mechanisms were developed to separate the grain on the tray. The capacity of winnowing is about 25 kg/hr.

I.A.R (2006) evaluated an existing prototype soybean thresher for performance and reported that the threshing efficiency, cleaning efficiency, grain damage, scatter loss and throughput capacity obtained with Samsoy-2 variety are 80 %, 70 %, 2 %, 1.94 % and 23 kg/hr respectively, while the values obtained with TAS 1485-ID variety were 86%, 64%, 1.6 %, 2.2 % and 21 kg/hr respectively. It was then concluded that the best combination of cylinder speed and feed rate that gave the highest threshing efficiency was 900 rpm cylinder speed and 20 kg/hr feed rate with both varieties.

Hyetson (2003) also worked on an existing I.A.R soybean thresher, where some missing components of the thresher were identified and replaced then the thresher was evaluated based on the performance using some parameters. After the evaluation, the best performance with TAS1485-ID variety at cylinder speed of 850 rpm and feed rate of 20 kg/hr was obtained. This combination has 98 % threshing efficiency, 2.99 % mechanical grain damage, 75 % cleaning efficiency, 2.99 % scatter loss and 22 kg/ hr throughput capacity. Also the result showed that threshing efficiency increases with increase in cylinder speed for both varieties. The mechanical grain damage also increases with feed rate and cylinder speed for both varieties but Samsoy- 2 has higher grain damage than TAS1485-ID variety. The cleaning efficiency decreases with an increase in feed rate in both varieties but with an increase in speed, Samsoy- 2 appears to have higher cleaning efficiency than the TAS1485-ID variety. The scatter loss increases with speed and feed rate in both varieties but TAS1485-ID has the highest loss than Samsoy 2. The throughput capacity also increases with increase in cylinder speed and feed rate for both varieties with Samsoy- 2 having higher output capacity than the TAS1485-ID.

Oforka (2004) modified the existing institute (IAR) soybean thresher and obtained the best performance combination at a cylinder speed of 850 rpm, feed rate of 30 kg/h with samsoy- 2 variety at 10 % moisture content of the grain. Also from his results the values of the parameter obtained are 96 % threshing efficiency, 2.86 % mechanical grain damage, 97 % cleaning efficiency 2.86 % scatter loss and 33 kg/hr throughput capacity.

Sessiz et al. (2007) designed and tested concaves made of different materials with respect to threshing efficiency, power requirement and specific power consumption at various feed rates and drum peripherals speed.

The threshing machine had peg tooth drum and was powered by 4 kW electricity motor. From the test results, the speed and feed rate were found to have a significant effect ($P<0.01$) on power requirement. The power requirement increased with increasing feed rate and drum peripheral speed. The specific power consumption decreases with increasing feed rate. Threshing efficiency decreases with increasing feed rate and increased drum peripheral velocity significantly improved the threshing efficiency. The highest threshing efficiency was achieved with the chromium type of concave, followed by PVC, the sheet iron and the rubber plate. The threshing efficiencies values as obtained using the drum peripheral speed of 14.66 m/s and feed rate of 1080 kg/h for each concave type are given as 92.8 % was gained using the chromium concave, which is the highest followed by 90.92 % using the PVC concave, 87.51 % was gained with the steel plate concave and 81.54 % was gained using the rubber concave plate.

The PVC and chromium concave beaters had the lowest power consumption with the highest threshing efficiency values. Hence, the use of PVC and chromium type concaves reduced product loses as well as power cost. The trials proved that the lowest threshing efficiency was gained with the rubber covered concave, whereas the highest value was obtained with the chromium contra beater.

Anusorn et al. (2008) developed and evaluated an axial flow soybean thresher. Machine crop parameters affecting the performance of the soybean thresher were evaluated. The

threshing mechanism consists of a threshing drum rotating inside a two section concave. The threshing drum consists of a peg-tooth type having an open threshing drum. The diameter and length of the drum were 420 mm and 930 mm respectively. The concave was made up of a mild steel rod with rod spacing of 25 mm. The clearance between the concave and the threshing drum was fixed at 40 mm.

During the tests, four drum speeds 400, 500, 600 and 700 rpm and three feed rates 360, 540 and 720 kg/hr were used for testing. The average moisture contents of grain used in the test were 32.88 (29.09) % (w.b), 22.77 (18.72) % (w.b) and 14.34 (16.78) % (w.b). The most commonly grown soybean variety KKU-35 grown in Thailand was used for the test. The performance evaluation of the developed thresher was assessed in terms of output capacity, threshing efficiency, grain damage, grain losses and power requirement. The performance evaluation shows that at grain moisture content of 14.34% (w.b), feed rate of 720 kg/hr and a drum speed of 700 rpm with an average power of 1.85 kW, the output capacity, threshing efficiency, grain damage and grain loss were found to be 214 kg/hr, 99.49 %, 0.22 % and 0.80 % respectively.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The material used for the design of the machine was selected based on the design considerations. The experimentation for the performance evaluation was also carried out based on some experimental techniques. The determination of component sizes and the detailed description of the machine are also given.

3.1 Materials

3.1.1 Selection of the materials for the thresher

Materials were selected for various components of the thresher depending on the function and strength required by each of the components;

Gauge 18 mild steel metal sheet was selected for the construction of the feed hopper.

Mild steel (C1040) is selected for the shaft design. This was selected based on the strength and also it is locally available.

Angle iron of size 250 mm × 250 mm ×3 mm was chosen for the frame of the thresher. This was selected considering the heavy weight of the other components of the thresher the frame is to support

Mild steel metal sheet of gauge 16 was also selected for the sieve plate.

The blower was also constructed using galvanized steel plate of gauge 18. Gauge 16 mild steel metal sheet was used for the shaker.

Various sizes of pulleys used are selected based on the values of diameters obtained from the speed ratios.

3.2 Methods

3.2.1 Design considerations

Various factors are considered in the design and construction of the improved soybean thresher.

The thresher is operated using a 4.5 kW diesel engine. This was chosen due to lack of frequent electricity supply and it is also cheaper than the petrol engine. The diesel engine can also be operated at desirable speeds. The speed of 700 rpm was chosen as the optimum speed for the operation of the machine. This was chosen considering the optimum speed of 850 rpm used by Oforka (2004) which results to higher grain damage and higher scatter loss due to the high speed. Vertical flow was chosen for the direction of flow of the threshed material for simplicity in design. The size of the sieve openings (oblong openings of 8 mm wide and 10 mm long) was used taking into consideration the average size of the soybean grain that was determined by Huji (2002) to be 5.28 mm wide, 6.39 mm long and 4.69 mm thick. The angle of repose of 17.50^0 as determined by Huji (2002) was used for the determination of the size of the feed hopper.

3.2.2 Design Calculations

3.2.2.1 Angle of repose

The angle of repose was calculate to be 17.50^0 by Huji (2002) using the formula shown below

$$\tan^{-1} A = \frac{y}{x} \quad 3.1$$

Where

y = Height of material from the flat ground to the apex

x = Radius of material from centre of material to the edge of the bowl

A =Angle of repose

3.2.2.2 Determination of the size of feed hopper

The size of the feed hopper was estimated to allow feeding in of the whole stalk of the soybean into the hopper for threshing. Because of the bulky nature of the soybean plant, the hopper was enlarged so that it can take more material at a time in order to increase the capacity.

The hopper was designed having a trapezoidal shape. The size of the hopper was made up of 49 mm length, 20 mm width and 15 mm depth.

3.2.2.3 Determination of weight of fan blades and the air discharge through the blower:

i) Weight of fan blades (w)

$W = \partial g v$ (Hannah 1984) 3.2

Where

∂ = Density of fan blade i.e steel (kg/m^3)

g = Acceleration due to gravity (m/s^2)

v = Volume of the fan blades (m^3)

v = Length x width x thickness of the blades (m^3)

iii) Air discharge through the blower

$Q = v \times D \times w$ (Joshi, 1981) 3.3

Where,

v = Velocity of air required for cleaning (m/s)

D = Depth of air stream over the sieve (m)

Q = Air discharged rate (m^3/s)

W= Width over which air is required (m)

Also

$v = \frac{2\pi r N}{360}$ (Hannah and stephen1984) 3.4

Where,

N= fan speed in (rpm)

r= distance between the centre of the shaft to the apex of the fan blade

Q=0.118m/s

3.2.2.4 Determination of pulley dimensions

The dimension of the pulley was determined using the following expression

$N_1 D_1 = N_2 D_2$ (Hannah and Stephen 1984) 3.5

Where

N_1 = Speed of drive pulley (diesel engine)

D_1 = Diameter of drive pulley

N_2 = Speed of thresher pulley

D_2 = Diameter of thresher pulley

i) From the expression above, D_2 which is the diameter of the thresher pulley was calculated as:

$D_2 = \frac{N_1 D_1}{N_2}$ 3.6

D_2=140 mm

ii) Estimated pulley dimension for fan

The following expression was also applied to calculate the diameter of the fan pulley.

$N_2 D_2 = N_3 D_3$ 3.7

Where

N_3 = Speed of fan

D_3 = Diameter of fan pulley

From the expression 3.7 above, D_3 was estimated as:

$$D_3 = \frac{N_2 D_2}{N_3} \qquad 3.8$$

D_3=163 mm

Estimation of pulley dimension for shaker

$$N_3 D_3 = N_4 D_4 \qquad 3.9$$

Where

N_4 = Speed of shaker

D_4 = Diameter of shaker pulley

From the equation 3.9, D_4 was calculated as:

$$D_4 = \frac{N_3 D_3}{N_4} \qquad 3.10$$

D_4=325mm

3.2.2.5 Estimation of belt lengths

The belt length was estimated using the expression established by Hannah and Stephen in 1984

$$L = 2c + 1.57(D - d) + \frac{(D-d)^2}{4C} \qquad 3.11$$

Where

L = effective length of belt

C = centre distance from drive to driven pulley

D = outside diameter of drive pulley

d = diameter of driven pulley

The above equation 3.11 was be used to estimate the belt length L_1, L_2, L_3, L_4 *and* L_5

Where

L_1 = 211cm -------length of belt from petrol engine to thresher pulley

L_2 = 92cm----------- length of belt from thresher pulley to collector pulley

L_3 = 152cm ---------length of best from thresher pulley to shaker pulley

3.2.2.6 Calculation of belt speeds

The belt speeds was calculated using the equation:

$N = \frac{V}{\pi D}$ (Hannah and Stephen 1984) 3.12

Where

V = belt speed (m/s)

N = drive speed (rpm)

D = diameter of drive pulley (m)

Hence

$V = N\pi D$ 3.13

Using the equation 3.13 above the various belt speeds V_1, V_2, *and* V_3 were calculated.

V_1 = 5.1 m/s--------- -speed of belt from petrol engine to thresher (m/s)

V_2 = 5.12m/s----------speed of belt from collector to shaker m/s)

V_3 = 6.8 m/s-----------speed of belt from thresher to fan (m/s)

3.2.2.7 Calculation of belt tension

The tension on each of the belts involved in the thresher was calculated using the following expression.

$T = S_t r$ (kWm) Hannah and Stephen (1984) 3.14

Where,

S_t = difference in tens of tight side and slack side of belts. S_1 & S_2

T= 0.372kN

But

Torsional moment (m_t) = $\frac{9550 \text{ x power}}{\text{Speed}}$ (Hall and Hollowenko, 1982)

And

$$M_t = (S_1 - S_2)\, r \qquad 3.15$$

$$M_t = 0.031\text{kN}$$

3.2.2.8 Determination of the shaft diameter

Design of a shaft involves determination of the minimum diameter of the shaft material that can withstand certain loading conditions. Shaft may be subjected to torsion, to bending, to axial tension or compression or to a combination of any or all of these actions. Therefore there is the need to take all of the above into consideration to avoid shaft failure. The selected material used for the shaft in this machine is medium carbon steel (C1040). The material has the following strength properties as stated by ASME, (1948).

Yield stress, S_y of 568.7MN/m^2

Tensile stress S_t of 668.8 MN/m^2

To get the shaft diameter (d) using the relationship

$$d^3 = \frac{16}{\pi S_a}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \text{ (Hall, 1984)} \qquad 3.16$$

where

S_a = 90.3 x 10^3 kN/m^2

K_b = 1.5 (constant)

$K_t = 1.0$ (constant)

$M_b = 0.232$ kNm

$M_t = 0.031$kNm

The minimum safe shaft diameter is calculated to be 27mm.

3.2.3. Description of the soybean thresher

The improved soybean thresher was designed and constructed with the following modifications;

1. An enlarged feed hopper which is bigger than that of the IAR soybean thresher.

2. Threshing unit with triangular threshing drum that has knife edge spikes at the sides of the concave.

3. Blower unit with additional fan blades.

Other components similar to that of the IAR soybean thresher includes; Shaker mechanism, grain outlet, grain collector, transmission units, sieve plate and the supporting frame.

The feed hopper has a trapezoidal shape with higher capacity than the existing one. It is constructed from gauge 18 mild steel metal sheet, it form the feeding chute through which the soybean plants are feed into the threshing unit.

The threshing unit was made up of cylinder, beaters and a perforated concave plate. The threshing cylinder also houses a threshing drum that consist of a long triangular shaped member on which a series of rasp bars are attached along the three edges. This cylinder drum is mounted on the bearing and is rotated in a perforated trough-like member, called the "Concave". An auger is located below the threshing drum to convey the material into a collecting tray in the shaker unit. The clearance between the free ends of the beaters and the concave is 6mm. The seize of the threshing unit was increased to a larger size than the existing threshing unit of the IAR soybean thresher by increasing the diameter and the depth of the threshing drum. Additional rasp bars in form of cutting knives were also added around the hopper section that covers the threshing drum. This was to enable the vegetative material of the soybean to be cut into pieces for easy threshing.

The shaker unit was located directly below the threshing cylinder and it consists of a collecting tray and a sieve. This unit is to collect the threshed material and separate the grains from the chaff through a reciprocating motion provided by the main source of power of the thresher.

The blower unit consists of a four-blade fan that provides air current that assists in separating the grain from the chaff. The fan is located at a distance below the perforated concave.

The sieve plate was constructed using gauge 16 mid steel metal sheet and is positioned inside the shaker tray. It covers the entire dimension of the tray and also extend outwards in such a way that it is just below the fan.

The grain collector is located just below the sieve plate to collect the cleaned threshed grains.

The transmission unit consist of a thresher pulley, a fan pulley and a shaker pulley whose various diameters were determined. It also consists of a series of bearings, shafts and V-belts of variable lengths. The thresher is powered by a 4.5kW diesel engine.

The thresher has a structural frame unto which all other components were mounted.

3.2.4. Performance evaluation of the improved soybean thresher

After construction the machine was evaluated on the following parameters:

3.2.4.1 Threshing efficiency, Te (%)

This parameter was used to determine the threshing ability of the improved soybean thresher. It is the ratio of the quantity of unthreshed grain in sample to the total quantity of grain in sample

$$T_e = 100 - \frac{Q_u}{Q_t} \times 100$$ (Ndirika, 1994) 3.17

Where

Q_u = quantity of unthreshed grains in sample (kg)

Q_t = Total quantity of grain in sample (kg)

3.2.4.2 Mechanical (visible) grain damage M_D (%).

This parameter was used to determine the quantity of grains damaged during threshing. It is the ratio of the quantity of broken grains collected in sample to the total quantity of grains in sample. (Ndirika, 1994) and it is given as

$$M_D = \frac{Q_b}{Q_t} \times 100$$ 3.18

Where

Q_b = quantity of broken grains in sample (kg)

Q_t = Total quantity of grain in sample (kg)

3.2.4.3 Cleaning efficiency C_e (%)

This is the ratio of the weight of the grain collected at the grain outlet to the weight of the total mixture of grain and chaff received at the grain outlet. (Ndirika ,1994) and it is given as

$$C_e = \frac{W_t - W_c}{W_t} \times 100 \qquad 3.19$$

Where

W_t = Weight of total mixture of grain and chaff received at the grain outlet (kg)

W_c = Weight of chaff at the main outlet of the thresher (kg)

3.2.4.4 Scatter Loss, S_L (%)

During the threshing operation some grains were lost due to scattering. Such grains were determined using the formula below;

$$S_L = \frac{Q_L}{Q_t} \times 100 \qquad 3.20$$

Where

Q_L = Quantity of grains scattered around the thresher after threshing operation (kg)

Q_t = Total quantity of grain in sample (kg)

3.2.4.5 Grain throughput capacity, Te (kg/hr)

This is the capacity of the thresher in terms of the total quantity of threshed materials in sample per unit time. Grain throughput capacity was calculated as done by Ndirika (1994), as;

$$T_C = \frac{Q_s}{T} \qquad 3.21$$

Where

Q_s = Quantity of threshed grain collected after a threshing operation (kg)

T = Time taken for a complete threshing operation (hr)

3.2.4.6 Moisture content (%)

The moisture content of the threshed grains was determined on wet basis using the oven drying method. The moisture content was calculated using the formula from ASAE (1972) as

$$M_{wb} = \frac{W_w - W_d}{W_w} \times 100 \qquad 3.22$$

Where

W_w = Weight of wet sample before drying (g)

W_d = Weight of sample after drying (g)

M_{wb} = Moisture content on wet basis (%)

3.2.5 Experimental Procedure

Three experimental factors used in carrying out the experiment are:

1) Feed rate, F. Three levels of feed rate i.e 1.0 kg/hr, 1.5 and 2.0 kg/hr were used.
2) Cylinder speed, S. The cylinder speeds used was at five different levels; These are at 300 rpm, 400 rpm, 500 rpm, 600 rpm and 700 rpm.
3) Moisture content M. Three levels of moisture contents; 10%, 13% and 14% were used for the experiment.

Using the three experimental factors above i.e F, S and M, a total of 45 experiments with three replications were conducted in order to determine the range of feeding rate, cylinder speed and moisture content that gives the best performance of the machine. At each combination, the threshed materials were collected at the outlets, cleaned and weighed. After threshing, the portion of the material containing unthreshed grains (grain and stalk) were collected, separated and weighed.

The experiment was carried out in three replicates making 45x3 experiments and the average was determined. At the end of the experiment the following results are obtained.

Q_o = Quantity of clean grains collected at the grain outlet after threshing (kg)

Q_u = Quantity of un threshed grains in sample (kg)

Q_b = Quantity of broken grains in Sample (kg)

Q_L = Quantity of grains scattered around the thresher after threshing operation (kg)

Q_s = Quantity of threshed grains collected after a threshing operation (kg)

$Q_s = Q_o + Q_L$

Q_t = Total quantity of grain in sample (kg)

$Q_t = Q_u + Q_s$

W_t = Weight of chaff and grains at outlet of thresher (kg)

W_c = Weight of chaff at outlet of thresher

T = Time taken for complete threshing operation (hr)

3.2.6 Experimental design

A completely randomized block design experimental was used. A layout of 5 levels of cylinder speed (300 rpm, 400 rpm, 500 rpm, 600 rpm and 700 rpm) by 3 levels of feed rates (1.0 kg/hr, 1.5 kg/hr and 2.0kg/hr) and 3 levels of moisture contents (10%, 13% and 14%) in a complete randomized block design form was used in three replications as shown in appendix i .

3.2.7 Analysis of result

The result obtained from the experiment was subjected to some graphical and statistical analyses. The statistical tool used was the Analysis of Variance ANOVA where the degree of freedom (DF), the sum of square (SS) and the mean square (MS) were calculated.

The F-calculated value was compared with the F-tabulated in order to determine the level of significance between the variables.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The soybean thresher constructed was used to carry out the performance evaluation. The result of the mean performance parameter for the soybean thresher at three moisture contents for different speeds and feed rates are presented. The result of the mean values of performance parameters for the soybean thresher at five levels of speeds for different feed rates are also presented in this chapter. The analysis of variance and the Duncan multiple range test carried out are also presented below.

4.1 Mean Values Of Performance Parameters For The Soybean Thresher At Three Moisture Contents For Different Speeds And Feed Rates

The result of the performance of the thresher at three moisture contents for different speeds and feed rates is shown in appendix iv. The graphs in Fig. 4.1 to 4.5 are used to represent the result.

4.1.1 Effect of moisture content on threshing efficiency at different feed rate

The result of the performance evaluation of the soybean thresher carried out shows the mean threshing efficiency at different combination of moisture content and feed rate. This result is shown in appendix iv. While the effect of these variables on threshing efficiency is shown in Fig 4.1. A high threshing efficiency of 99% was obtained at the lowest moisture content of 10% and at the lowest feed rate of 1.kg/min. This result is higher than that obtained by Oforka (2004) which was 96%. There is lower efficiency at higher feed rate and higher moisture content. This indicates that threshing efficiency increases with decrease in moisture content and feed rate.

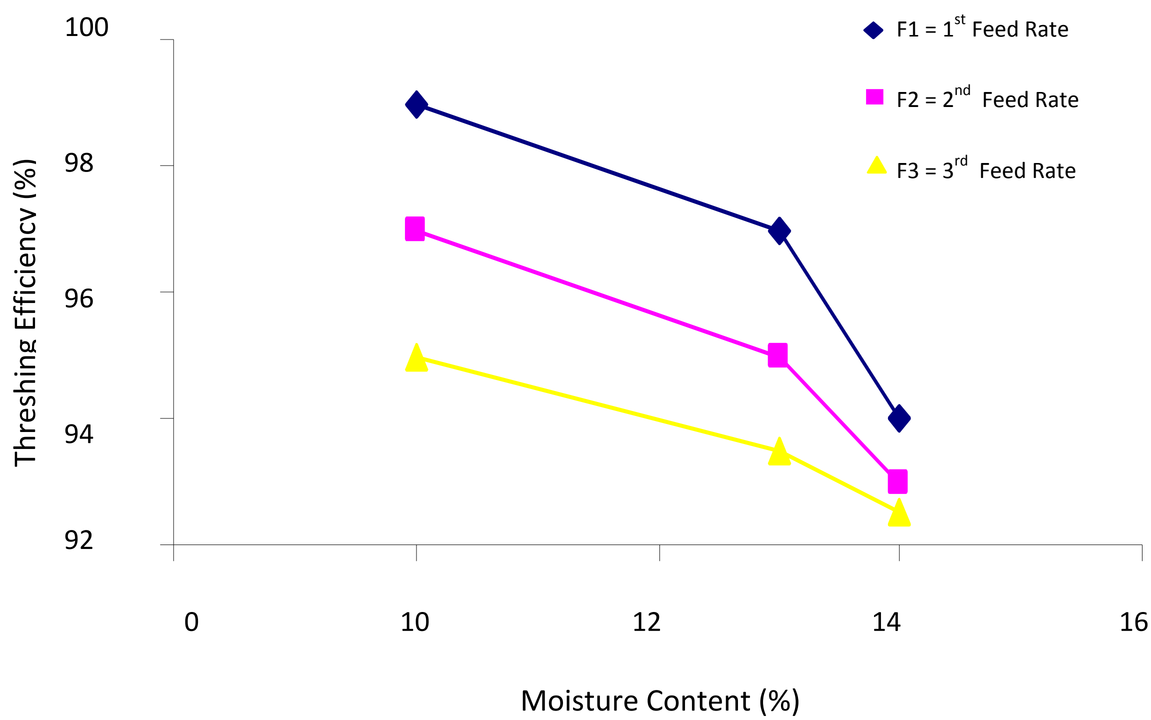

Fig.4.1.Effect of Moisture Content on Threshing Efficiency at Various Feed Rate

4.1.2 Effect of moisture content on cleaning efficiency at different feed rate

Also Appendix v shows the means of the cleaning efficiency at different moisture level and feed rate. From Appendix v, Fig.4.2 was obtained and is presented below. It shows that the drier the material to be threshed, the higher the cleaning efficiency. Cleaning efficiency of 95% was achieved at the lowest moisture level of 10% and at the lowest feed rate. Hyetson(2003) got a lower cleaning efficiency of 75% at a moisture content of 15% and feed rate of 20kg/hr. As the feed rate is increased from F1 to F3, the corresponding efficiency reduces at different moisture level.

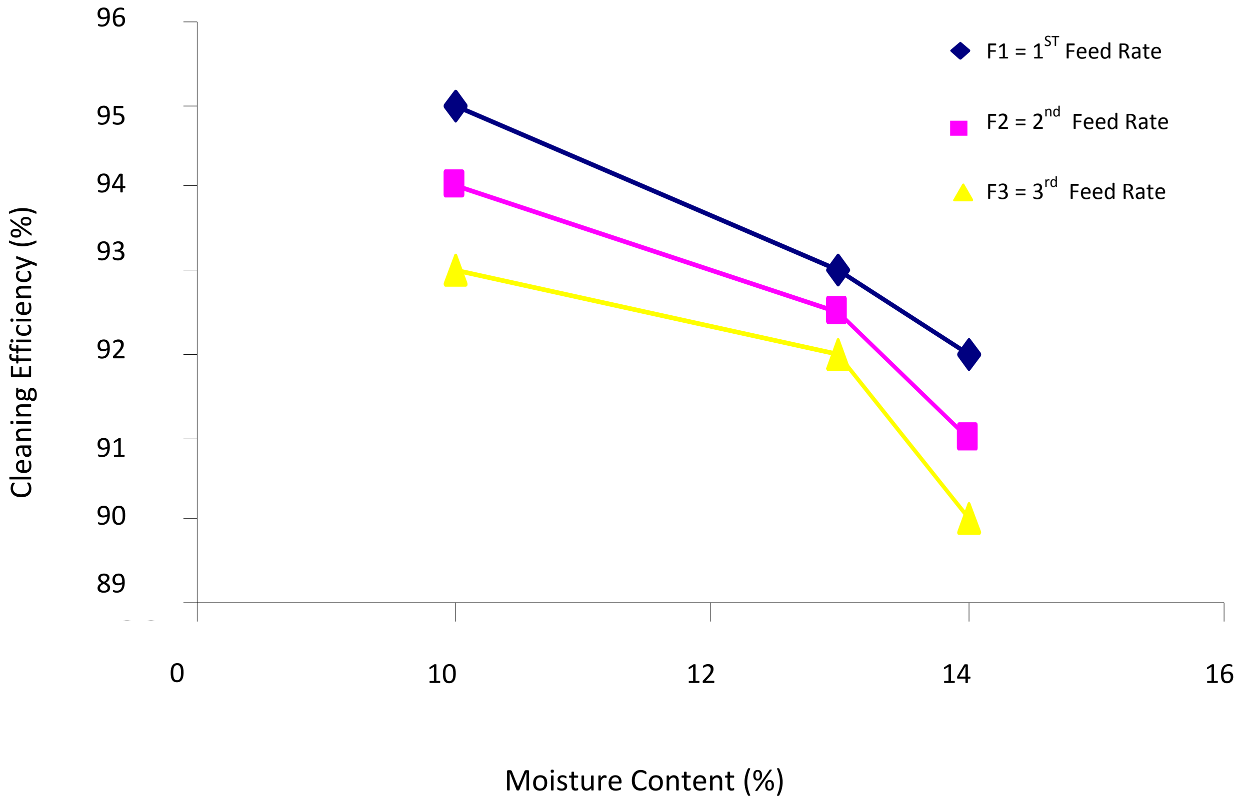

Fig.4.2 Effect of Moisture Content on Cleaning Efficiency at various Feed Rate

4.1.3 Effect of moisture content on grain damage at different feed rate

The mean values of the mechanical grain damage with respect to different moisture content and various feed rate is also shown on appendix vi. The values from this table are represented by Fig 4.3. The quantity of grain that is broken during threshing increases with a decrease in moisture content and an increase in feed rate. A high grain damage of 1.0% at a moisture content of 10% occurs with the highest feed rate. The lowest grain damage of 0.92% was at the highest moisture content of 14% and occurs with the lowest feed rate. This could be compared to that of Oforka (2004) where he obtained a high grain damage of 2.86% at moisture content of 10%.

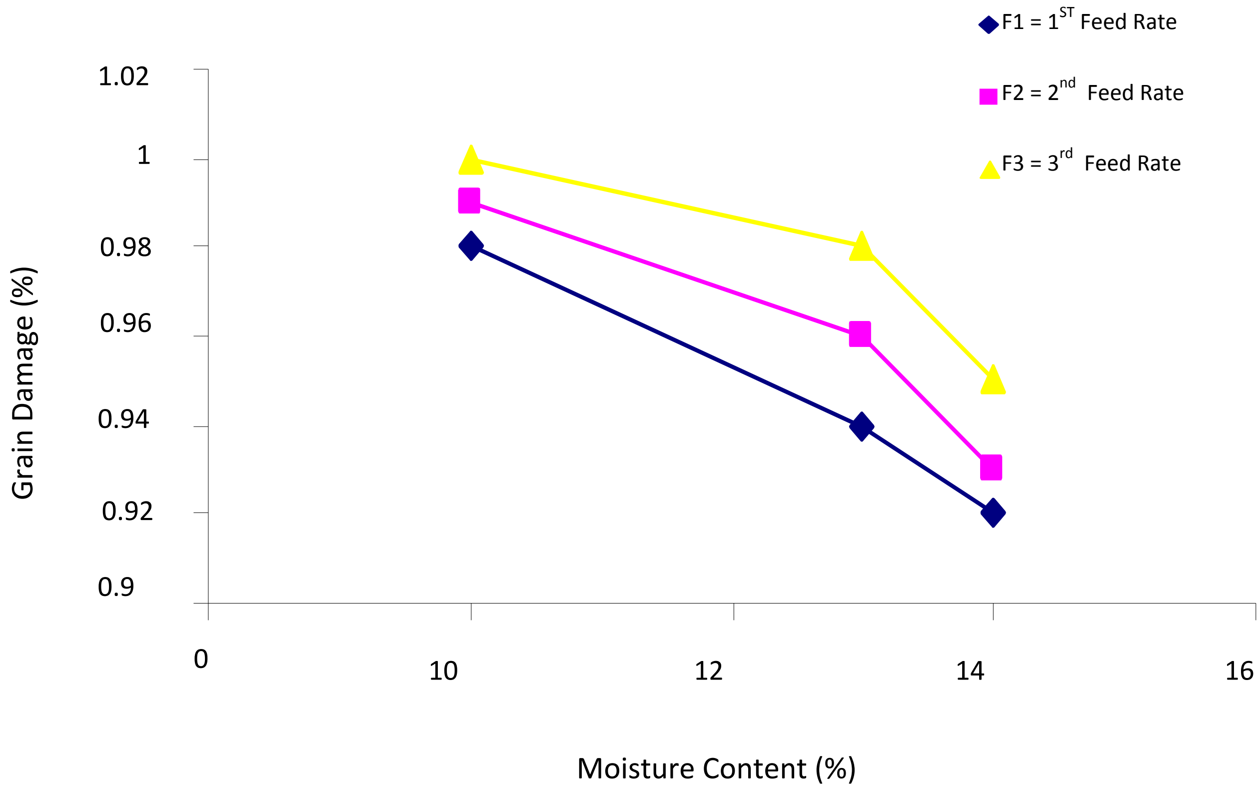

Fig.4.3 Effect of Moisture Content on Grain Damage at Various Feed Rate

4.1.4 Effect of moisture content on scatter loss at different feed rate

From appendix vii the result of the performance of moisture content on scatter loss at various feed rate is presented in fig 4.4 below. An increase in feed rate at lower moisture content lead to increase in scatter loss. The highest scatter loss of 2.7% occurs at a moisture content of 10% with the highest feed rate while a low scatter loss of 2.0% occurs at the highest moisture content of 14% with the lowest feed rate.

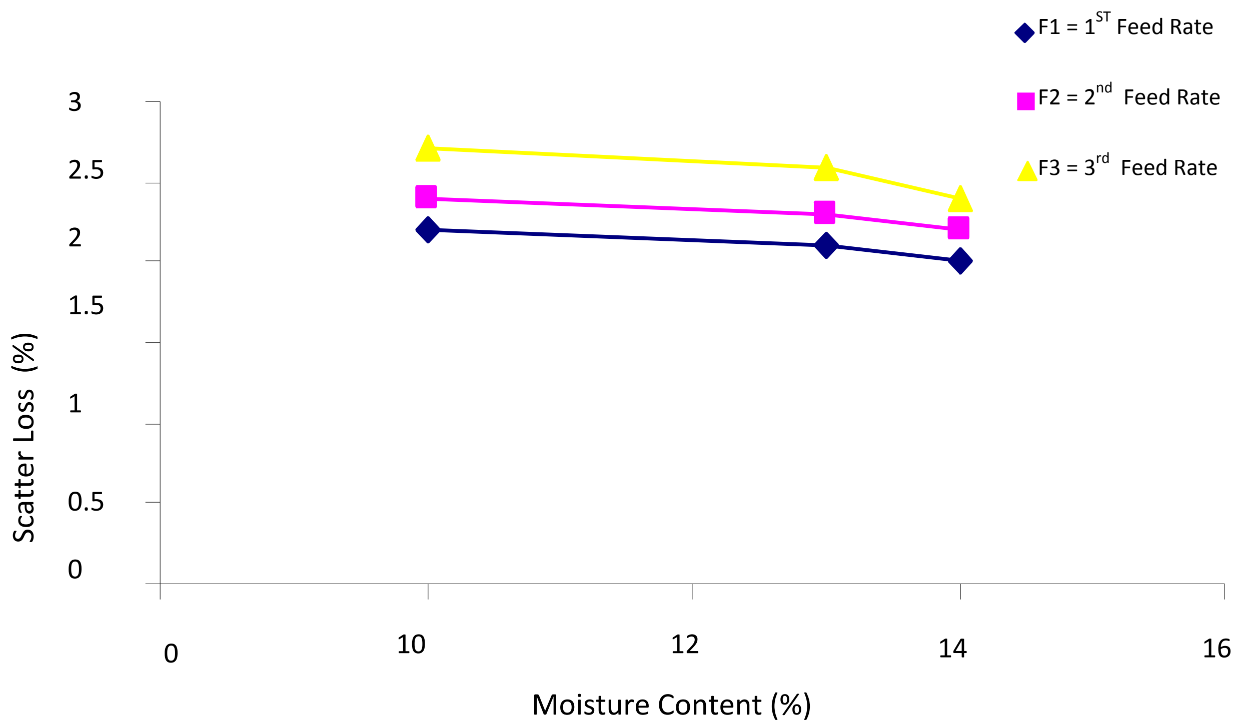

Fig.4.4 Effect of Moisture Content on Scatter Loss at Various Feed Rate

4.1.5 Effect of moisture content on grain throughput capacity at different feed rate

Appendix vii gives the means values of the grain throughput capacity at different moisture content and feed rate Fig 4.5 gives the representation of these data. From the figure, it could be seen that throughput capacity increase with a decrease in moisture content and an increase in feed rate. It shows that throughout capacity increase with all level of feed rate as moisture content is reduced. A throughput capacity of 25.5kg/min was obtained at the lowest moisture content of 10% and at the highest feed rate of F3. Ofoka (2004) also obtain a throughput capacity of 33kg/hr at moisture content of 10%.

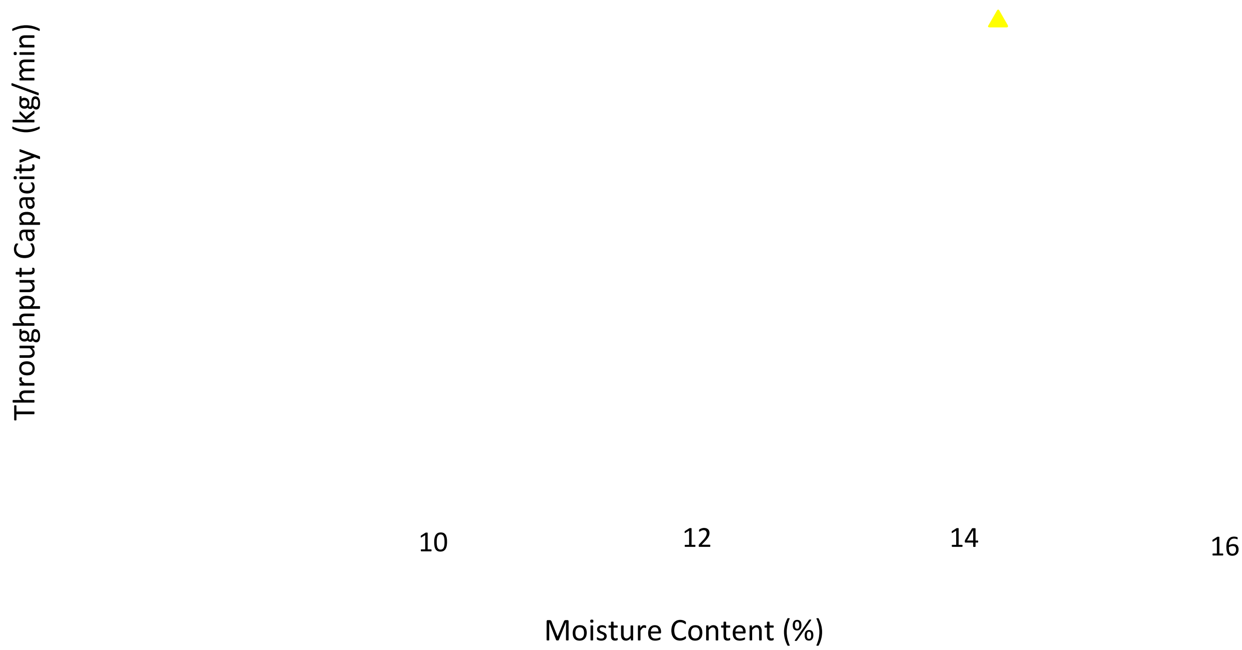

Fig.4.5 Effect of Moisture Content on Grain Throughput Capacity at Various Feed rate

4.2 Mean Values of Performance Parameters for Soybean at five Levels of Cylinder Speed for Different Feed Rate at Same Moisture Level.

Performance of the thresher at different speed and different feed level but same moisture content is shown in appendix iv. While the effect of speed on the different performance parameters is represented in the figures below.

4.2.1 Effect of cylinder speed on threshing efficiency at different feed rate

The mean value of threshing efficiency as they are affected by different speed at various feed rate is shown in appendix iv. The threshing efficiency was obtained at a constant moisture content of 10%. The result is shown in Fig 4.6 below. Threshing efficiency increases with an increase in speed and feed rate. The lowest threshing efficiency occurs as the feed rate is increased. A high threshing efficiency of 99% was obtained at the highest speed of 700 rpm with the lowest feed rate. The R^2 values of the three feed rates also shows that at both feed rates, there is a close relationship between the speed and the threshing efficiency. The lowest threshing efficiency of 92% occurs at the lowest speed of 300 rpm with the highest feed rate. Anurson (2008) also obtain a TE of 99.4% at speed of 700rpm

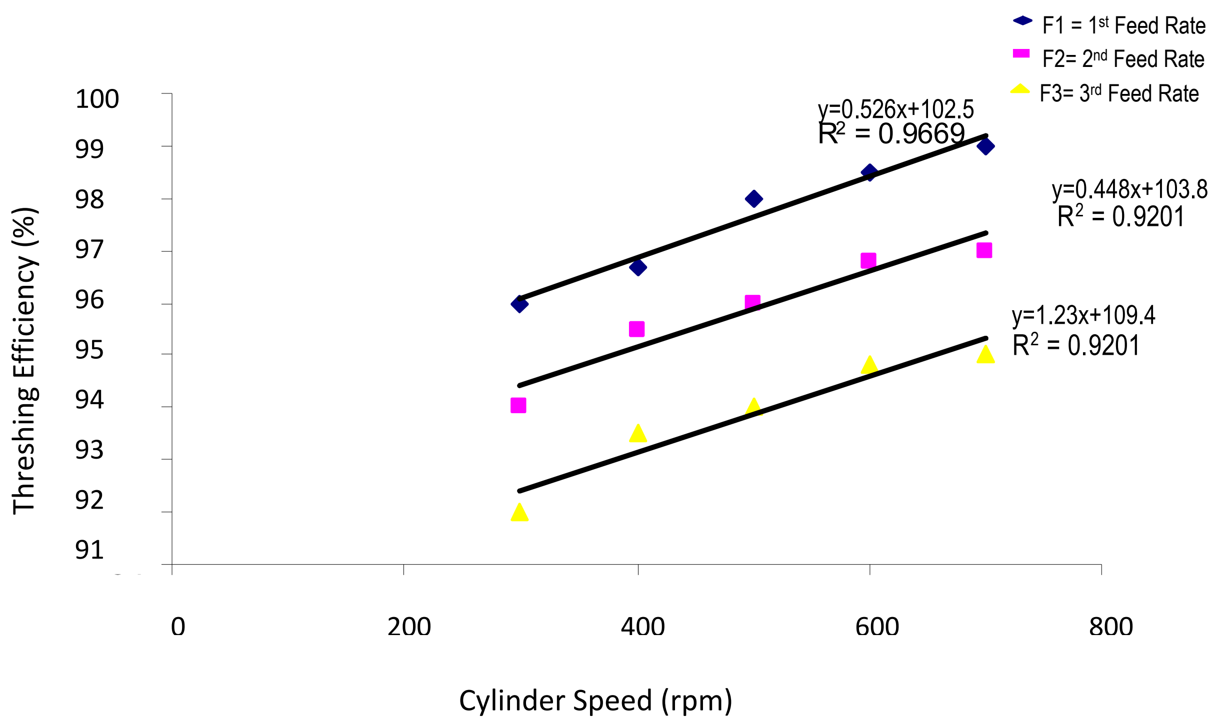

Fig.4.6 Effect of Cylinder Speed on Threshing Efficiency at Various Feed Rate

4.2.2 Effect of cylinder speed on cleaning efficiency at different feed rate

Also considering only moisture content of 10% the mean value of the cleaning efficiency with regards to how they are affected by speed is given in appendix v. This result is given in the graph shown below. Increased in cylinder speed, increases the speed of the fan which eventually increases the cleaning efficiency. A cleaning efficiency of 95% was obtained at a high speed of 700rpm with the lowest feed rate. The lowest cleaning efficiency of 89% was obtained at lowest speed of 300rpm with the highest feed rate. I.A.R (2006) thresher gave a cleaning efficiency of 70%. The R^2 obtained for the three feed rate also shows a close relationship between speed and the cleaning efficiency.

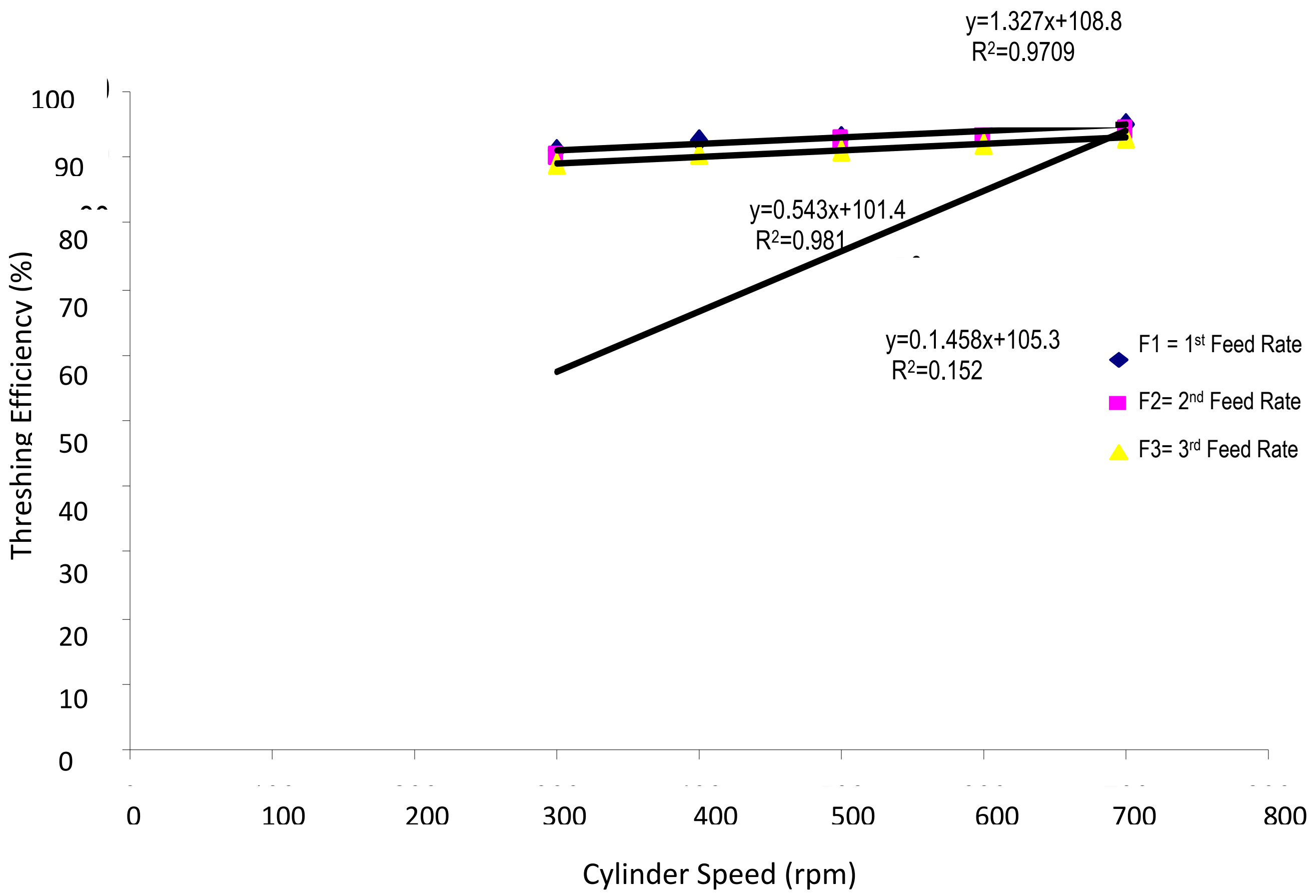

Fig.4.7 Effect of Cylinder Speed on Cleaning Efficiency at Various Feed Rate

4.2.3 Effect of cylinder speed on mechanical grain damage at different feed rate

From appendix vi, the result of the performance of cylinder speed on the mechanical grain damage at various feed rate was used to produce the graph in Fig 4.8. From the figure it shows that an increase in speed gives a linear increase in grain damage with all the levels of feed rate. A low grain damage of 0.90% was at the speed of 300rppm with the lowest feed rate while a high grain damage of 1.01% was at the highest speed of 700rpm with the highest feed rate. The R^2 values of feed rate (F3) and F2 i.e. 0.9897 and 0.9897 indicates that there is a very close relationship between the cylinder speed and the mechanical grain damage while the R^2 value of feed rate F1, which is equal to 1.00 shows a perfect or linear relationship between the cylinder speed and the mechanical grain damage.

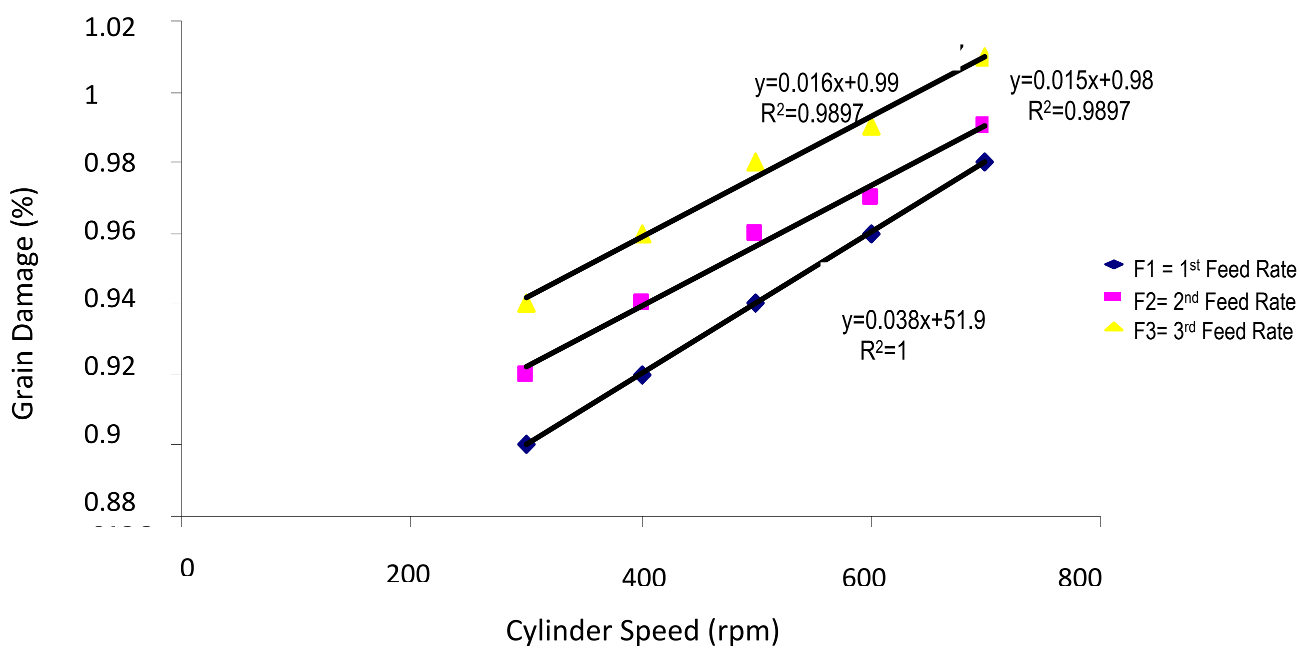

Fig.4.8 Effect of Cylinder Speed on Grain Damage at Various Feed Rate

4.2.4 Effect of cylinder speed on scatter loss at different feed rate

The result of the mean values of scatter loss as they are affected by the cylinder speeds and different feed rated is seen in appendix vii. The data in Appendix vii is represented in Fig 4.9. From the graph, it shows that an increase in cylinder speed during threshing at constant moisture content of 10% increases the scatter loss. A scatter loss of 2.70% was obtained at the highest speed of 700rpm with the highest feed rate while the lowest scatter loss of 0.76% was at the lowest speed of 300rpm with the smallest feed rate. With more material being fed into the hopper, and at a higher speed, more grain tends to scatter around the machine. The R^2 values also shows a close relationship between the speed and scatter loss.

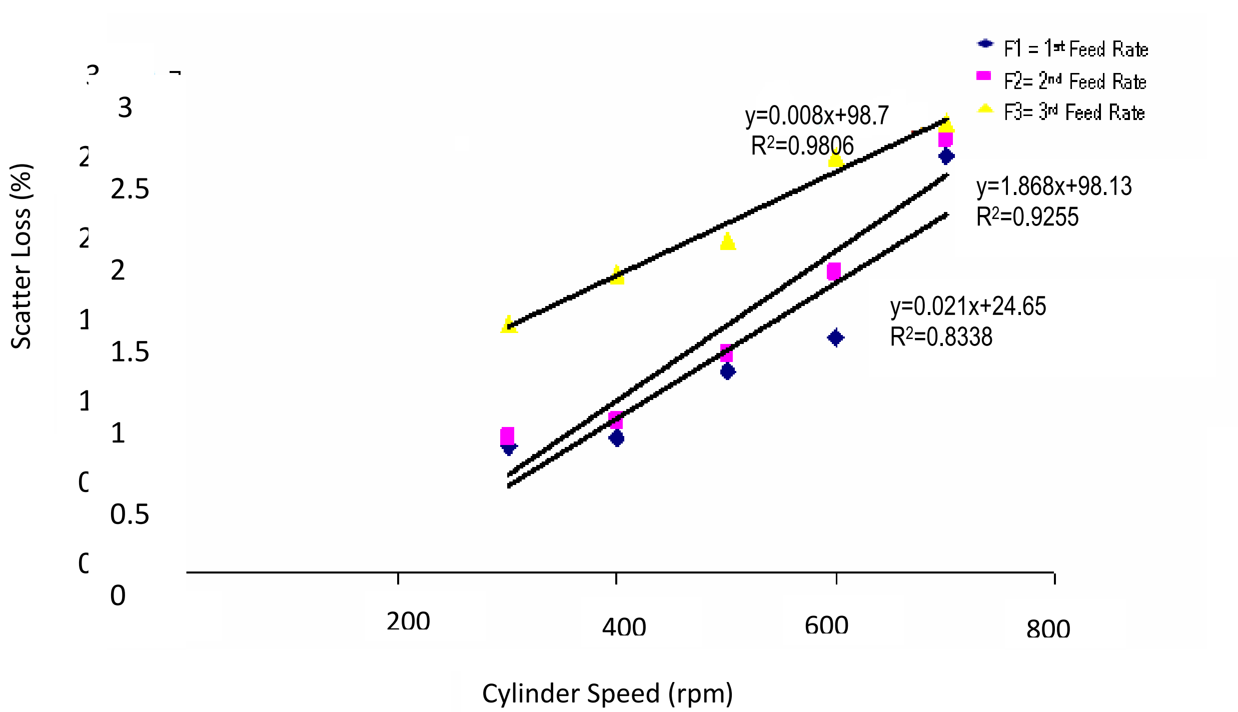

Fig.4.9 Effect of Cylinder Speed on Scatter Loss at Various Feed Rate

4.2.5 Effect of cylinder speed on grain throughput capacity at different feed rate

The performance of the speed on the grain throughput capacity with different levels of feed rate is given in appendix vii. This result is also represented in Fig 4.10, the throughput capacity of the machine tend to increase with the speed and the level of feed. The higher the feed rate and at an increase in speed, throughput capacity increases. A high throughput capacity of 25.5kg/hr was obtained at the highest speed of 700rpm and highest feed rate of F3. The R^2 values for both levels of feed rate indicate that there is also a close relationship between the speed and the grain throughput capacity.

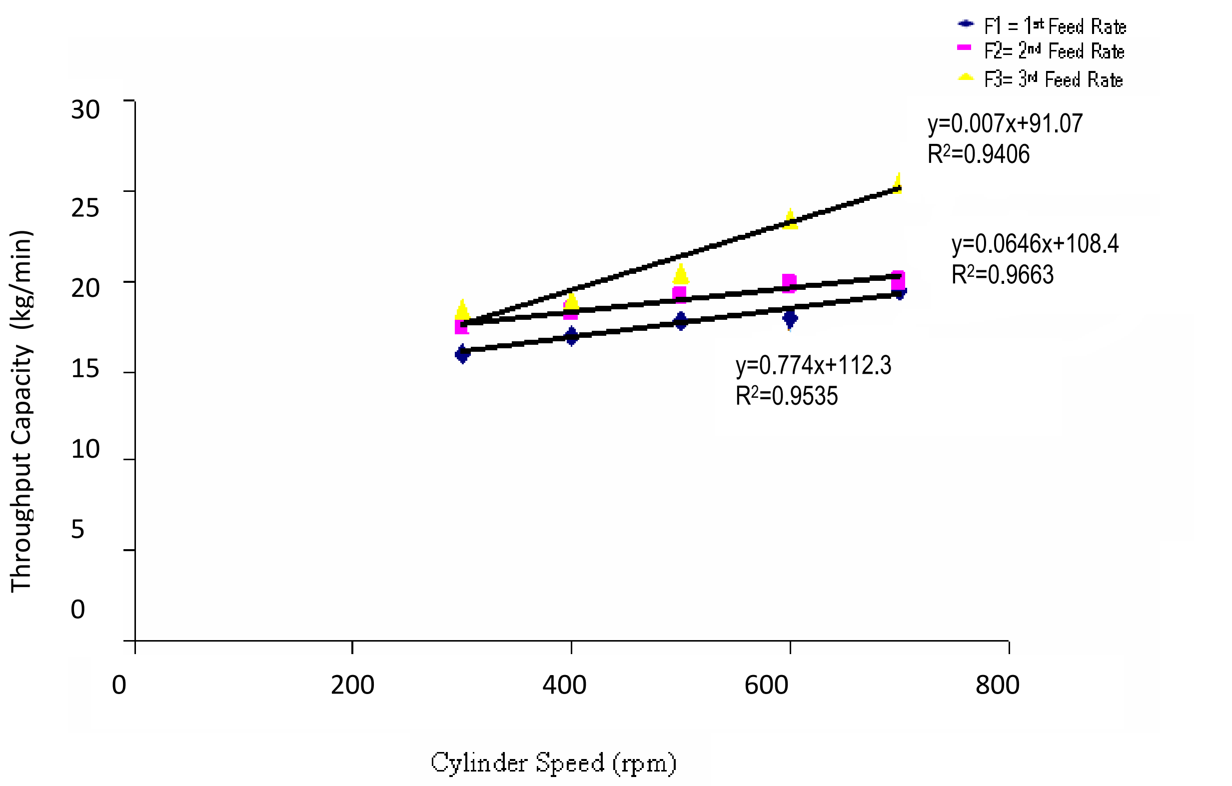

Fig.4.10 Effect of Cylinder Speed on Throughput Capacity at Various Feed rate

4.3. Results of the Analysis of Variance

4.3.1 ANOVA for threshing efficiency

From the result of the statistical analysis carried out using ANOVA see appendix x, it could be seen that the F-Calculated is greater than the F-Tabulated. This indicates that the level of the effect of the in-dependable variables (feed rate, speed and moisture content) on the threshing efficiency is significant.

Table 4.1 Dependable Variable; Threshing Efficiency.

Source	DF	sum of square	mean square	F value
Model	46	56.607	1.23	1.65
Error	88	65.496	0.744	
Total	134	122.104		

Source	DF	Type I SS	Mean Square	F Value	
Rep	2	1.837	0.9185	1.23	NS
Feed	2	14.637	7.319	9.83	*
moisture	2	0.015	0.007	0.01	NS
Speed	4	13.585	3.396	4.56	*
Feed*Moisture	4	2.385	0.596	0.80	NS
Feed*Speed	8	6.104	0.763	1.03	NS
Moisture*Speed	8	5.393	0.674	0.91	NS
Feed*Moisture*Speed	16	12.652	0.791	1.06	NS
Error	88	65.496	0.744		

Also from the Duncan multiple range test for threshing efficiency (Appendix x) it shows that feed rate 1 has the highest effect on the threshing efficiency while feed rate 2 and 3 are of the same level of effect on the threshing efficiency. In terms of moisture content, all the levels of moisture contents are having the same effects on the threshing efficiency hence they carry the same letter A. With regards to speed, speed 5 which is the highest speed is having the highest effect on the threshing efficiency while speed 4, 1 ,2 and 3 are having the same level of effect.

The analysis of variance shows that the interaction between the three variables, feed rate, moisture content and cylinder speed, from the analysis it shows that out of the mean of the three variables, only the mean of the moisture content is not significantly different. The interaction between the feed and moisture and between the moisture and speed is also not significant while the interaction between feed and speed, feed with moisture and speed are all significant at probability level of 0.05.

4.3.2. ANOVA for cleaning efficiency

Table 4.2 Dependable Variable; Cleaning Efficiency

Source	DF	Sum of square	Mean square	F value
Model	46	0.316	0.007	2.64
Error	88	0.229	0.006	
Total	134	0.544		

Source	DF	Type I SS	Mean Square	F Value	
Rep	2	0.055	0.028	10.64	*
Feed	2	0.004	0.002	0.70	NS
Moisture	2	0.014	0.007	2.78	NS
Speed	4	0.040	0.010	3.87	*
Feed*M0isture	4	0.030	0.008	2.90	*
Feed*Speed	8	0.038	0.005	1.81	NS
Moisture*Speed	8	0.044	0.006	2.12	*
Feed*Moisture*Speed	16	0.090	0.009	2.17	*
Error	88	0.2223	0.003		

The value of F-Calculated in the Table 4.2 is greater than the value of F-Tabulated hence there is a significant difference between the means of the in-dependable variable on the dependable variable which is the cleaning efficiency.

From appendix x, the Duncan test shows that in terms of feed rate , all the levels of feed rates used have the same effect on the cleaning efficiency but the effect on cleaning efficiency by moisture content at levels 1 and 3 are similar. Speed 5, 4 and 3 have similar effect on the cleaning efficiency. Speeds 3 and 1 are also having similar effect i.e. B while speeds 2 and 1 are also of similar effect on the cleaning efficiency.

With respect to the cleaning efficiency, the ANOVA shows that feed and moisture are not statistically significant while speed is statistically significant at 0.05 probability. The interaction between feed and speed is not significant while the interaction between the feed versus moisture, moisture versus speed and feed is not significant while the interaction between feed versus moisture, moisture versus speed and feed versus moisture versus speed are all statistically significant at 0.05 probability

4.3.3. ANOVA for mechanical grain damage.

Table 4.3 Dependable Variable; Mechanical Grain Damage.

Source	DF	Sum of square	mean square	F-value
Model	46	217.911	4.7371981	2.58
Error	88	161.822	1.839	
Total	134	379.733		

Source	DF	Type I SS	Mean Square	F Value	
Rep	2	13.511	6.756	3.67	*
Feed	2	5.911	2.956	1.61	NS
Moisture	2	1.111	0.556	0.30	NS
Speed	4	73.437	18.359	9.98	*
Feed*Moisture	4	59.378	14.844	8.07	*
Feed*Speed	8	3.941	0.492	0.27	NS
Moisture*Speed	8	25.185	3.148	1.71	NS
Feed*Moisture*Speed	16	35.437	2.215	1.20	NS
Error	88	161.82	1.839		

From table 4.3 it could be seen that the F - calculated is greater than the F-Tabulated, therefore there is a significant difference between the means of the feed rate, speed and moisture content on the mechanical grain damage.

The Duncan test also shows that the effects of the different levels of feed rates are not significantly different; hence they are all carrying the letter A. All the levels of moisture contents are also not significantly different. Speed 5 is having the highest effect on the grain damage while speed 1 is of the least effect on the grain damage with the letter C.

The ANOVA shows that at probability level of 0.05, feed and moisture are not statistically significant while it shows that speed is significant. In terms of the interaction only feed versus moisture is significant while speed versus moisture and feed versus moisture versus speed are all not statistically significant at 0.05 probability.

4.3.4. ANOVA for scatter loss.

Table 4.4 Dependable Variable; Scatter Loss

Source	DF	Sum of square	Mean square	F-value
Model	46	45.625	0.992	1.720
Error	88	50.705	0.576	
Total	134	96.330		

Source	DF	Type I SS	Mean Square	F Value	
Rep	2	1.562	0.781	1.36	NS
Feed	2	9.881	4.941	8.57	*
Moisture	2	2.475	1.238	2.15	NS
Speed	4	5.079	1.270	2.20	NS
Feed*Moisture	4	6.899	1.722	2.99	*
Feed*Speed	8	7.148	0.893	1.55	NS
Moisture*Speed	8	2.735	0.342	0.59	NS
Feed*Moisture*Speed	16	9.856	0.616	1.07	NS
Error	88	50.705	0.576		

The ANOVA result from table 4.4 indicates that the F-Calculated is greater than the F-Tabulated, hence there is a significant difference between the effects of the means of feed rate, moisture content and speed on scatter loss.

From the Duncan test result the effect feed rate 2 and 3 are not significantly different, hence they are ranked with the same letter B. While feed rate 1 is ranked with letter A. In terms of the effect of the different levels of moisture content on the scatter loss, all the moisture content levels are having the same level of impact on scatter loss.

The ANOVA for scatter loss shows that moisture and speed are not significant while feed is significant. The interaction between feed and moisture is significant while interaction of feed versus speed, moisture versus speed and feed versus moisture versus speed are not significant at probability of 0.05.

4.3.5. ANOVA for grain throughput capacity.

Table 4.5 Dependable Variables; Grain Throughput Capacity

Source	DF	Sum of square	Mean square	F-value
Model	46	1980.963	43.064	7.92
Error	88	478.252	5.435	
Total	134	2459.215		

Source	DF	Type I SS	Mean Square	F Value	
Rep	2	5.748	2.874	0.53	NS
Feed	2	1505.437	752.719	138.50	**
Moisture	2	24.948	12.474	2.30	NS
SPEED	4	196.252	49.063	9.03	*
Feed*Moisture	4	74.696	18.674	3.44	*
Feed*Speed	8	29.526	3.691	0.68	NS
Moisture*Speed	8	88.237	11.029630	2.03	NS
Feed*Moisture*Speed	16	56.119	3.507	0.65	NS
Error	88	47	8.252	5.435	

In table 4.5, there is a significant difference between the means of feed rate, speed and moisture content on the grain throughput capacity.

Considering the Duncan test for the effect of the independent variables on the throughput capacity it could be seen that feed rate 3 is having the highest effect followed by feed rate 2 and 1. All the levels of moisture contents are having similar effect on the throughput capacity hence it shows that they are not significantly different. With regards to the speeds, speed 5 and 4 are not significantly different and are having similar effect on the throughput capacity.

From table 4.5 it shows that the levels of feed and speed are statistically significant on throughput capacity while moisture is not significant. It also shows that the interaction of feed versus moisture is also significant while the interactions between feed versus speed, moisture versus speed and feed versus moisture versus speed are not significant at 0.05 probability level.

4.5 Comparison between the Old and the New Thresher

Table 4.6 shows the comparison between the old and new threshers using student t-test. It table reveals that of all the performance parameters of the soybean, only the threshing efficiency and the cleaning efficiency were statistically significant at 1% and 5% levels respectively. The means of the other parameters were not statistically significant at 5% and 1% levels.

Table 4.6 Comparative Evaluation Of Performance Between Old And New

Parameters	Average values		Calculated	Tabulated	Significance
	New (%)	Old (%)			
Threshing Eff. (%)	99	80	3.68	2.06	*
Cleaning eff. (%)	95	70	18.2	2.306	* *
Mechanical grain damage (%)	1.01	2.0	1.05	2.306	N.S
Throughput capacity (kg/hr)	25.5	23	0.85	2.306	N.S
Scatter loss (%)	2.7	1.94	1.03	2.306	N.S

* Significant at 5% level

* * Highly significant at 1% level
N.S Not significant

CHAPTER FIVE

5.0 Summary, Conclusion and Recommendation

5.1 Summary

From the result of the performance evaluation carried out on the soybean thresher it indicates the following results;

1. Threshing efficiency increased with a decrease in feed rate and moisture content at a higher speed
2. Cleaning efficiency was observed to increase at a decreasing feed rate and moisture content with an increase in the cylinder speed.
3. Mechanical (visible) grain damage increased with an increase in cylinder speed and feed rate but at lower moisture content.
4. Scatter loss increased with an increase in cylinder speed and feed rate at lower moisture content. The highest lost was recorded at a cylinder speed of 700 rpm .
5. Throughput capacity also increased with an increase in cylinder speed and feed rate at lower moisture content.

Also based on the result of the analysis of variance carried out, it was discovered that all the F-Calculated to show the level of significance of the effect of the means of the in-dependable variables i.e. feed rate, moisture content and speed on the dependable variables i.e. threshing efficiency, cleaning efficiency, scatter loss, grain damage and grain throughput capacity are greater than the F-Tabulated. This implies that there is a significant difference between the means of the in-dependable variables with the dependable variables.

5.2 Conclusion

Based on the specific objectives, a prototype soybean thresher was designed and constructed with modification on the threshing cylinder, the fan blades and the feed hopper. The performance evaluation of the improved soybean thresher was carried out and from the result it shows that the thresher has a great potential in mechanizing the threshing process of soybean. From the comparative analysis between the performance of the old IAR soybean thresher and the improved soybean thresher, it shows that the improved thresher has better performance than the old IAR soybean thresher.

5.3 Recommendation

From the analysis and discussions of the performance result of the test on the soybean thresher and in order to improve on the performance, the following recommendations should be considered;

1. It was noticed from the operation of the machine that grains are being lost through the hopper, hence the hopper should be enlarged.
2. To improve on the cleaning efficiency additional fan housing in form of a suction mechanism should be developed to remove finer particles from the threshed grains.
3. An alternative means of improving the cleaning efficiency is that an additional sieve of smaller diameters should be added below the existing one. This will allow the finer particles from the threshed grains to fall while the clean grain is collected from the grain outlet.
4. An on-farm trail of the improved soybean thresher should be carried out by the farmers for assessment

REFERENCES

Amir, U.K. (1990): Dual model all crops thresher for Equatorial conditions. *Agricultural mechanization in Asia* 21(4):11-14

Anuson, V. and Vilas, M. S. (2006): Machine Crop Parameters Affecting Performance of an axial flow soybean thresher. *Agricultural Mechanization in Asia.* 37(3):32-37.

Ayagi, M.H. (1994): Evaluation of a locally built soybean thresher. Unpublished B.Engr. Degree Project presented to Department of Agric Engineering. Ahmadu Bello University, Zaria.

Bartsch, J.A., Haugh,C.G., and Athow, K.L. (1979):Impact damage to soybean seed. *American Society of Agric Engineers Paper.* 79:30-37

Cain,D.F. and Holmes,R.G. (1977): Evaluation of soybean seed impact damage .*American society of agric Engineers paper* 71:15-52.

Choudlbury,W. And Kaul,R.N. (1979): Comparative Evaluation of Threshing Wheat by some Machine and Manual Test Report. DAE/T9/9.

Doque , A .T. (1999):Western region research Centre. U.S Department for Agriculture. Berley, Califonia.

F.A.O, (1980):World estimation of soybean production. *Food and Agricultural Organization* bulletin-80.

Foster, B. (1967):Operating condition for maximum efficiency in the use of cleaning and grading machines for grains. Annual report of institute of Agric engineers U.K. 22(40):20-25.

Hall, S.A. and Holowenko, R.A. (1982): *Machine Design.* Schallms Outline Series. Pp. 112.

Hannah,J. and Stephen, R.C. (1984): *Mechanics of Machine* 3rd Edition, Edward Arnol Ltd London.

Hoki,M. and Esmay,M. L. (1979): Soybean production and processing in developing countries. *Agricultural Mechanization in Asia.* 20(1):83-85.

Hopsen, H.J. (1969): Farm Implement for Arid and Tropical Regions. Agricultural Development Paper No. 19, *Food and Agricultural Organization.* Rome.

Huji, H. (2002): Determination of some physical and mechanical properties of cowpea and soybean. Unpublished B.Eng. thesis of Agric Engineering Department A.B.U Zaria.

Hyetson, R.D. (2003): Performance Evaluation of a Soybean Thresher. Unpublished B. Engr. Thesis Submitted to the Agric Engineering Department, A.B.U. Zaria.

I.A.R. Report (2005-2006): Improvement of an I.A.R. Soybean thresher. I.A.R. Progress Report of Research Projects Undertaken in 2005-2006. I.A.R. Ahmadu Bello University, Zaria. Pp. 152-153.

I.A.R (2006):Agricultural equipment prototypes. Annual report Agricultural Mechanization. Institute for Agric Research, A.BU. Zaria.

I.R.R.I (1974): International Rice Research Institute. Annual report. Philippines.

Joshi, H.C. (1981): Design and Selection of Thresher Parameter and Components. *Agricultural mechanization in Asia, Africa and Latin America*. 11(2):61-63.

Kanafojski,J. and Karwoski,P.(1976): Processing soybeans; *Soybean digest.* 5(1):6-9.

Kepner,R.A. and Bainer,R. (1992): Design and selection of thresher parameters and components.
Agricultural Mechanization in Asia. 8(3):28-30.

Marina, D.B. (1991): Post Harvest and processing Technologies of African Staple Foods: Food and Agricultural Services. Bulletin (89), Rome, Pp. 164-170.

Mazvimavi, K. (1997): An over view of Sorghum and Millet Production and Utilization in Zimbabwe Semi arid regions. Pp.18.

Mesquita,C.M. and Hoag, A. (1989): Soybean threshing devices. *American society of Agricultural engineers.* 12(1):15-18.

Mesquita,C.M. and Hanna,M.A. (1993): Mechanics of soybean threshing. *Agricultural Mechanization in Asia.* 20(4):15-17.

Mohsenin, N.N. (1970): *Physical Properties of Plant and Animal materials.* 2nd edition Gordon and Breach science. New York, U.S.A pp 31-33.

N.C.R.P.S (1988): National Coordinated Research Project on soybean, Proceedings of 8th Annual National soybean Conference at Makurdi, Nigeria.

Ndirika,V.I.O . (1984): Development and performance evaluation of a millet thresher. *Journal of Agricultural Technology* 1(1):2-5

Oforka, O.M. (2004): Improvement of IAR Soybean Thresher: Unpublished B. Engr. Thesis of Agric Engineering Department, A.B.U. Zaria.

Paulsen,E.T. (1978): Crack formation in corn kernels subject to impact. Transaction of *American society of Agricultural Engineers.* 22(4);889-892.

Policarpio,S.A. and Mcmannamy,J.A. (1974): The development of the I.R.R.I potable thresher. *Agricultural Mechanization in Asia.* 19(2):59-65.

Rijpma, J.P., Darries, H.C.P. and Owaa, S.E. (1997): Development of Separator for Soybean. *Agricultural Mechanization in Asia.* 34(2);52-55.

Sessiz,A., Pinar,Y. and Konyuneu,T. (2007): Soybean Threshing Efficiency and Power Consumption for Different Concave Material. *Agricultural Mechanization in Asia.* 38(3):56-59.

Sharma, K.D. and Devnani,R.S. (1978): Threshing Studies on Soybean and Cowpea. *Agricultural Mechanization in Asia.* 11(1): 65-68.

Simonyan,K.J., Yiljep,Y.D.and Mudiare,O.J. (2006): Modelling the Cleaning Process Of a Stationary Sorghum Thresher. Agricultural Engineering International.The *CIGRE Journal.*8(1):14-15.

Simonyan, K.J. (2006): Mathematical Modelling of Grain Cleaning Process in Stationary Sorghum Thresher: Unpublished Ph.D Dissertation of Agricultural Engineering department. Ahmadu Bello University, Zaria.

Singh, B. (1968): Testing, Design and Selection of Soybean Machine. Annual Reports. G.B. Part University of Agriculture and Technology. U.K. Pp. 71.

Smith, K.J. and Huyser,W. (1987): World Distribution and Significance Of Soybean ; Improvement, Production and Uses: Second Edition. *American Society of Agronomy. International Journal*, 8(1):40-42.

APPENDIX I

Experimental Design

This is the field layout of 5 x 3 x 3 factorial experiment in a complete randomized block design with the cylinder speed at 5 levels (S_1, S_2, S_3, S_4 & S_5), feed rate at 3 levels (F_1, F_2, & F_3) and moisture content at 3 levels (M_1, M_2, & M_3) in three replications.

RI

$F_1M_1S_1$	$F_1M_2S_1$	$F_2M_1S_1$	$F_2M_2S_1$	$F_1M_3S_1$	$F_2M_3S_1$	$F_3M_1S_1$	$F_3M_2S_1$	$F_3M_3S_1$
$F_1M_1S_2$	$F_1M_2S_2$	$F_2M_1S_2$	$F_2M_2S_2$	$F_1M_3S_2$	$F_2M_3S_2$	$F_3M_1S_2$	$F_3M_2S_2$	$F_3M_3S_2$
$F_1M_1S_3$	$F_1M_2S_3$	$F_2M_1S_3$	$F_2M_2S_3$	$F_1M_3S_3$	$F_2M_3S_3$	$F_3M_1S_3$	$F_3M_2S_3$	$F_3M_3S_3$
$F_1M_1S_4$	$F_1M_2S_4$	$F_2M_1S_4$	$F_2M_2S_4$	$F_1M_3S_4$	$F_2M_3S_4$	$F_3M_1S_4$	$F_3M_2S_4$	$F_3M_3S_4$
$F_1M_1S_5$	$F_1M_2S_5$	$F_2M_1S_5$	$F_2M_2S_5$	$F_1M_3S_5$	$F_2M_3S_5$	$F_3M_1S_5$	$F_3M_2S_5$	$F_3M_3S_5$

RII

$F_2M_1S_3$	$F_1M_1S_1$	$F_1M_1S_2$	$F_1M_1S_4$	$F_2M_3S_1$	$F_1M_3S_1$	$F_1M_3S_4$	$F_1M_3S_4$	$F_1M_3S_5$
$F_2M_2S_3$	$F_1M_2S_1$	$F_1M_2S_2$	$F_1M_2S_3$	$F_1M_3S_3$	$F_2M_3S_3$	$F_2M_3S_5$	$F_2M_3S_2$	$F_2M_3S_4$
$F_1M_2S_4$	$F_2M_1S_4$	$F_1M_2S_5$	$F_2M_1S_1$	$F_3M_1S_1$	$F_3M_1S_3$	$F_3M_1S_4$	$F_3M_1S_2$	$F_3M_1S_1$
$F_1M_1S_3$	$F_2M_2S_2$	$F_2M_2S_4$	$F_2M_2S_1$	$F_3M_2S_3$	$F_3M_2S_1$	$F_3M_2S_2$	$F_3M_2S_4$	$F_3M_2S_5$
$F_2M_1S_5$	$F_2M_2S_5$	$F_2M_1S_2$	$F_1M_1S_5$	$F_3M_3S_2$	$F_3M_3S_3$	$F_3M_3S_1$	$F_3M_3S_5$	$F_3M_3S_4$

RIII

$F_1M_2S_4$	$F_2M_1S_3$	$F_1M_1S_3$	$F_2M_2S_3$	$F_1M_3S_4$	$F_1M_3S_2$	$F_1M_3S_1$	$F_1M_3S_3$	$F_1M_3S_5$
$F_1M_1S_1$	$F_1M_2S_1$	$F_2M_1S_4$	$F_2M_2S_5$	$F_2M_3S_1$	$F_2M_3S_4$	$F_2M_3S_5$	$F_2M_3S_2$	$F_2M_3S_3$
$F_1M_2S_5$	$F_2M_2S_4$	$F_1M_2S_2$	$F_2M_1S_2$	$F_3M_1S_3$	$F_3M_1S_1$	$F_3M_1S_4$	$F_3M_1S_5$	$F_3M_1S_3$
$F_2M_2S_1$	$F_1M_1S_4$	$F_1M_2S_3$	$F_2M_2S_2$	$F_3M_2S_2$	$F_3M_2S_3$	$F_3M_2S_5$	$F_3M_2S_3$	$F_3M_2S_2$
$F_1M_1S_2$	$F_2M_1S_1$	$F_1M_1S_5$	$F_2M_1S_5$	$F_3M_3S_4$	$F_3M_3S_4$	$F_3M_3S_1$	$F_3M_3S_4$	$F_3M_3S_2$

APPENDIX II

Anova For The Layout

Sources of variance	Df	SS	MS	F
Replications (r-1)		2		
Speed (S-!)		4		
Feed rate (f-1)	2			
Moisture content (M-1)		2		
Speed x federate (S-1)(F-1)	8			
Speed x moisture content (S-1)		8		
Federate x moisture content (F-1)(M-1)		4		
Speed x Feed rate x moisture content	16			
Error (SFM) (r-1)		88		
Total array (SFMr – 1)		**134**		

APPENDIX III

Design Calculations

Weight of fan blade

$W = \partial g v$ (Hannah 1984) 3.2

Where

∂ = Density of fan blade i.e steel = 7.83 x10^3 kg/m^3

g = Acceleration due to gravity = 9.8m/s^2

v = Volume of Fan blades = 16 gauge = 0.1304m^3

v = Length x width x thickness (gauge 18 of 0.00156m) x 4 blades

:. *W = 7.83 x 10^3 x 9.81 x 0. 435 x 0.105 x 0.00156 x 4*

W = <u>*21.89N*</u>

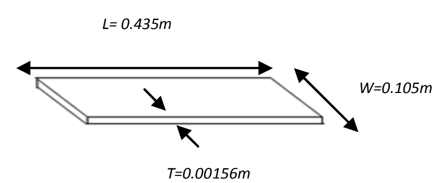

Fig. III.a Fan blade

Air discharge through the blower

$Q = v \times D \times w$ 3.3

Where

v = Velocity of air required for cleaning (m/s)

Speed of fan blade (N) is 600 rpm, the

Velocity $v = \frac{2\pi r N}{360} = \frac{2 \times 3.142 \times 600}{360}$m/s 3.4

v = 1.05 m/s

W = width over which air is to blow = 0. 45m

D = depth of air stream over the sieve = 0.25m

:. Q = 1.05 x 0.45 x 0.25

Q = 0.118 m^3/s

Pulley Dimensions

i. For threshing pulley

$N_1D_1 = N_2D_2$ 3.5

N_1= speed of motor pulley = 1400 rpm

N_2 = speed of thresher pulley = 700 rpm

D_1 = Diameter of motor pulley = 70 mm

D_2 = Diameter of thresher pulley

$$D_2 = \frac{N1D1}{N2} \quad 3.6$$

$$D_2 = \frac{1400 \times 700}{700} = 140 \text{ mm}$$

ii. For blower Pulley

$N_2D_2 = N_3D_3$ 3.7

$$D_3 = \frac{N_2D_2}{N_3} \quad 3.8$$

N_2 =700 rpm, N_3= 600 rpm and D_2 = 140mm

$$D_3 = \frac{700 \times 140}{600} = 163.\text{ mm}$$

iii. For Shaker Pulley

$N_3D_3 = N_4D_4$ 3.9

$$D_4 = \frac{N_3D_3}{N_4} \quad 3.10$$

Where N_3 = 600 rpm, N_4 = 300 rpm, D_3= 163 mm

$$D_4 = \frac{600 \times 163}{300} = 325 \text{ mm}$$

(iv) Belt Lengths

$$L = 2c + 1.57(D - d) + \frac{(D - d)^2}{4C} \qquad 3.11$$

Length of belt from prime mover to thresher pulley:

$$L = 2c + 1.57(D - d) + \frac{(D - d)^2}{4C}$$

Where

d = diameter of drive pulley = 7 cm

D= diameter of thresher pulley = 14 cm

C= centre to centre distance between drive pulley and driven pulley = 100cm

$$L_1 = 2 \text{ x } 100 + 1.57\,(14\text{-}7) + \frac{(14 - 7)^2}{4 \text{ x } 100}$$

$$L_1 = 211 \text{ cm}$$

Length of belt from thresher pulley to fan pulley

D = 16 3cm

D = 14 cm

C = 45 cm

$$L_2 = 2 \text{ x } 4.5 + 1.57\,(16.3 - 14) + \frac{(16.3 - 14)^2}{4 \text{ x } 45.0}$$

L_2 = 92 cm

Length of belt from thresher pulley to shaker pulley

$$L_3 = 2 \text{ x } 63 + 1.57\,(30 - 14) + \frac{(30 - 14)^2}{4 \text{ X } 63}$$

$$L_3 = 152 \text{ cm}$$

Calculation of Belt Speed

$$N = \frac{V}{\pi D} \qquad 3.12$$

But $V = N\pi D$ 3.13

Where

N = drive speed = 1400rpm

D = diameter of drive pulley = 70mm

$$V_1 = \frac{1400 \text{ x } 3.142 \text{ x } 0.07}{60} = 5.1 m/s$$

V_1 = 5.1m/s (speed of belt from prime mover to thresher)

Speed of belt from thresher to fan pulley

$$V_2 = \frac{600 \times 3.142 \times 0.163}{60} = 5.12m/s$$

Speed of belt from thresher to shaker pulley

$$V_3 = \underline{400 \times 3.142 \times 0.325} = 6.8m/s$$

Calculation of Belt Tension

The tension on each of the belts involved in the thresher was calculated using the following expression.

$T = S_t r$ (kWm) Hannah and Stephen (1984) 3.14

Where,

S_t = difference in tens of tight side and slack side of belts. S_1 & S_2

T= 0.372kN

But

Torsion moment (m_t) = $\frac{9550 \times power}{Speed}$ (Hall and Hollowenko, 1982)

And

$$M_t = (S_1 - S_2)\ r \qquad 3.15$$

M_t=0.031kN

Determination of Maximum Allowable Shearing Stress

The maximum allowable shearing stress using the ASME code can be obtained as the lowest value of 18% tensile stress (S_t) and 30% of yield stress (S_y). The allowable stress is further reduced by 25% when there is a key way in the shaft.

Thus,

$0.18\, S_t = 0.18\, (668.8\ MN/m^2) = 120.38 MN/m^2$

$0.30\, S_y = 0.30\, (568.7\ MN/m^2) = 170.61 MN/m^2$

The lowest value of the tensile stress is $120.38 MN/m^2$.

Since a key way is to be provided in the shaft.

Thus, the allowable shear stress (S_a) would be reduced by 25%

i.e $S_a = 120.38\, (1-0.25)\ kN/m^2 = 90.3 \times 103\ kN/m^2$

Torque required to thresh Soybean and Stalk is obtained as follows

$$P = Tw \qquad 3.16$$

$$T = \frac{P}{w}$$

Where

P = rated power of the engine = 4.5 kW

W = angular velocity

$$W = \frac{2\pi N}{60}$$

Where N = 1400rpm rated speed of the engine

$$W = \frac{2\pi \times 1400}{60} = 146.62\ rad/sec$$

$$T = \frac{4500}{146.62} = 30.69\ Nm = 0.03069 kNm$$

$$T = 0.031 kNm$$

The weight of the cylinder = 0.103kN

Weight of the Pulley = 0.25kN

Torque on shaft = 0.031kNm

- To get the total belt tension$(S_1 + S_2)$ using the relationship:

$$(S_1 - S_2)\, r = T \qquad 3.17$$

$$\frac{S_1}{S_2} = 3$$

$$(S_1 - S_2) \times 0.07m = 0.031kNm$$

$$S_1 - S_2 = 0.186kN$$

Also $S1 = 3S_2$

Substituting S_1

$$3S_2 - S_2 = 0.186kN$$

$$2S_2 = 0.186$$

$$S_2 = 0.093kN$$

To get S_1

$$S_1 = 3S_2 = 3x\ 0.093 = 0.279kN$$

Total belt tension = 0.093 + 0.279 = 0.372kN

Weight of Pulley and Belt tension is 0.23 + 0.372 = 0.622kN

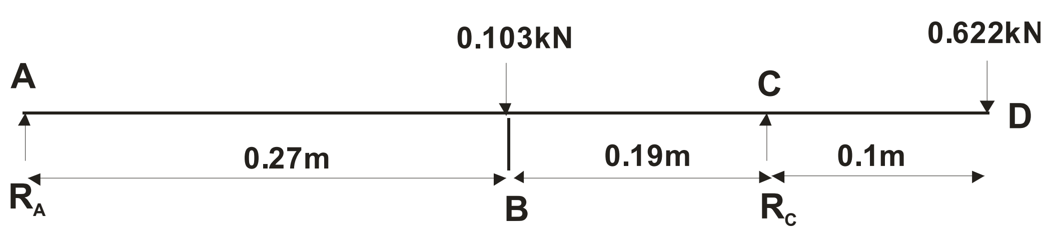

Fig.iii b. Reaction forces on the Shaft.

$$\sum V = 0$$

$$R_A + R_c = 0.103 + 0.622$$

$R_A + R_c = 0.725kN$

Also taking moments about point C

$\sum_{mc} = 0$

$R_A (0.46) - 0.103 (0.19) + 0.622 (0.1) = 0$

$R_A (0.46) - 0.01957 + 0.0622 = 0$

$$R_A = \frac{0.08177}{0.46} = 0.178kN$$

$R_A = 0.178kN$

To get R_c, substitute in equation (1) above

$0.178 + R_c = 0.725$

$R_c = 0.725 - 0.178 = 0.547kN$

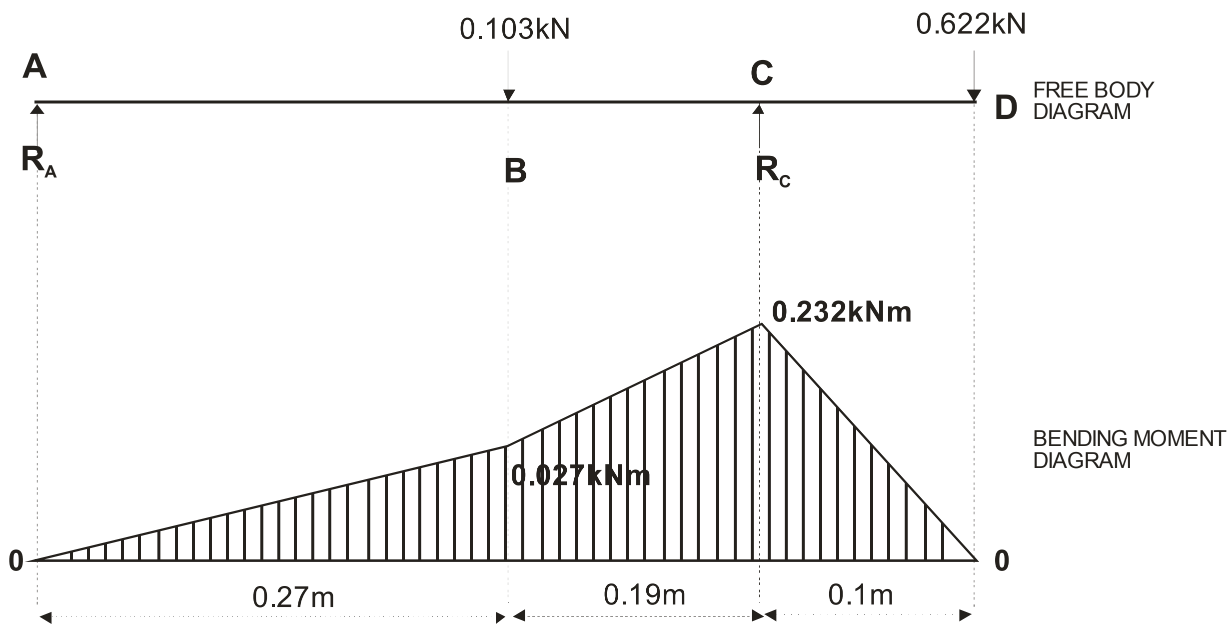

Fig.iii c. Free Body and Bending Moment Diagram.

To get the maximum Bending moment

B.M at point A and at point D = 0

B.M at B = 0.103 (0.27) = 0.0278kNm

B.M at C = 0.547 (0.46) – 0.103 (0.19)

= 0.252 -0.019

= 0.2324 kNm

Maximum Bending moment (M_b) = 0.232 kN

Determination of the Shaft Diameter

To get the shaft diameter (d) using the relationship

$$d^3 = \frac{16}{\pi S_a}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad 3.18$$

where

$S_a = 90.3 \times 10^3$ kN/m^2

$K_b = 1.5$ (constant)

$K_t = 1.0$ (constant)

$M_b = 0.232$ kNm

$M_t = 0.031$kNm

$$d^3 = \frac{16}{3.142 \times 90.3 \times 10^3}\sqrt{(0.232 \times 1.5)^2 + (0.031 \times 1.0)^2}$$

$$d = \sqrt[3]{0.0000197}$$

d =0.0270m

d = 27mm

Therefore the minimum safe shaft diameter is 27mm.

Calculation for Moisture Content

$$M_1 = \underline{W_1 - W_d} \quad x \;\; 100. \qquad 3.19$$

W_d

Where

M_1 = first moisture content

W_1 = initial weight of sample = 312 g

W_d = final weight of sample after oven dry = 284.2g

$$\therefore \quad M_1 = \frac{312 - 284.2}{284.2} \times 100 = 10\%$$

M_2 = second moisture content

W_2 = initial weight of sample = 292.8g

W_d = final weight of sample after oven dry sample = 284.5g

$$\therefore \quad M_2 = \frac{292.8 - 258.5}{258.5} \times 100 = 13\%$$

M_3 = third moisture content

W_2 = initial weight of sample = 165.3g

W_d = final weight of sample after oven dry sample = 145g

$$\therefore \quad M_3 = \frac{165.3 - 145}{145} \times 100 = 14\%$$

APPENDIX IV

The effect of speed and moisture content at various feed rate on threshing efficiency

Feed rate (kg/min)	Cylinder speed (rpm)	Threshing efficiency		
		14% moisture content	13% moisture content	10% moisture content
1.0	300	97	97.1	96
1.0	400	97.7	97.5	96.7
1.0	500	98.0	98	98
1.0	600	98.5	97	98.5
1.0	700	94	97	99
1.5	300	93	95	97
1.5	400	97	96	95.5
1.5	500	98	97	96
1.5	600	99	98	96.8
1.5	700	99.3	99.10	97
2.0	300	97	97	97
2.0	400	98	97.5	97
2.0	500	98.6	98	97
2.0	600	99.0	99	98
2.0	700	92.5	93.5	95

APPENDIX V

The effect of speed and moisture content at various feed rate on cleaning efficiency

Feed rate (kg/min)	Cylinder Speed (rpm	Cleaning efficiency		
		14% moisture content	13% moisture content	10% moisture content
1.0	300	82	80	91
1.0	400	89	85	92.5
1.0	500	90	90	93
1.0	600	91	91	94.5
1.0	700	92	93	95
1.5	300	86	87	88.90
1.5	400	91	86	91
1.5	500	90	89	92.5
1.5	600	91	92	93
1.5	700	91	93	94
2.0	300	91	90	89
2.0	400	90	89	90.5
2.0	500	92	92	91.0
2.0	600	93	93	92.0
2.0	700	90	92	93

APPENDIX VI

The effect speed and moisture content at various feed rate on mechanical grain damage

Feed rate (kg/min)	Cylinder Speed (rpm	Mechanical grain damage		
		14% moisture content	13% moisture content	10% moisture content
1.0	300	0.97	0.98	0.90
1.0	400	0.56	0.55	92
1.0	500	0.87	0.97	0.94
1.0	600	0.98	0.96	0.96
1.0	700	0.93	0.97	0.98
1.5	300	0.92	0.94	0.92
1.5	400	0.99	0.98	0.94
1.5	500	0.94	0.98	0.96
1.5	600	0.84	0.98	0.97
1.5	700	0.93	0.98	0.99
2.0	300	0.85	0.93	0.94
2.0	400	0.92	0.81	0.96
2.0	500	0.97	0.93	0.98
2.0	600	0.92	0.95	0.99
2.0	700	0.95	0.98	1.01

APPENDIX VII

The effect of speed and moisture content at various feed rate on scatter loss

Feed rate (kg/min)	Cylinder Speed (rpm	Scatter Loss		
		14% moisture content	13% moisture content	10% moisture content
1.0	300	0.15	0.75	0.76
1.0	400	0.56	3.5	0.80
1.0	500	1.1	0.97	1.20
1.0	600	1.2	1.91	1.4
1.0	700	2.0	2.3	2.3
1.5	300	3.4	4.7	0.8
1.5	400	2.5	0.58	0.9
1.5	500	1.5	0.58	1.3
1.5	600	1.21	1.4	1.8
1.5	700	2.1	2.4	2.6
2.0	300	0.9	0.44	1.5
2.0	400	0.75	0.90	1.8
2.0	500	0.86	0.84	2.0
2.0	600	0.99	1.0	2.5
2.0	700	2.41	2.5	2.7

APPENDIX VIII

The effect of speed and moisture content at various feed rate on throughput capacity

Feed rate (kg/min)	Cylinder Speed (rpm	Throughput capacity		
		14% moisture content	13% moisture content	10% moisture content
1.0	300	16	16	16
1.0	400	17	12	18
1.0	500	18	18	20
1.0	600	24	19	20
1.0	700	16	18	19.5
1.5	300	21	30	18
1.5	400	21	20	21
1.5	500	27	22	20
1.5	600	30	26	21
1.5	700	17.5	19.5	20
2.0	300	27	28	21
2.0	400	25	29	26
2.0	500	27	29	24
2.0	600	30	30	27
2.0	700	4.4	23.5	25.5

APPENDIX X

STATISTICAL EVALUATION OF THE IMPROVED SOYBEAN THRESHER.

1. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Class Level Information

Class	Levels	Values
Rep	3	1 2 3
Feed	3	1 2 3
Moisture	3	1 2 3
Speed	5	1 2 3 4 5

Number of observations 135

2. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Dependent Variable: TE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	46	56.6074074	1.2305958	1.65	0.0219
Error	88	65.4962963	0.7442761		
Corrected Total	134	122.1037037			

R-Square	Coeff Var	Root MSE	TE Mean
0.463601	0.881387	0.862714	97.88148

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Rep	2	1.83703704	0.91851852	1.23	0.2961
Feed	2	14.63703704	7.31851852	9.83	0.0001
Moisture	2	0.01481481	0.00740741	0.01	0.9901
Speed	4	13.58518519	3.39629630	4.56	0.0021
Feed*Moisture	4	2.38518519	0.59629630	0.80	0.5276
Feed*Speed	8	6.10370370	0.76296296	1.03	0.4234
Moisture*Speed	8	5.39259259	0.67407407	0.91	0.5156
Feed*Moisture*Speed	16	12.65185185	0.79074074	1.06	0.4026

Source	DF	Type III SS	Mean Square	F Value	Pr > F

Rep	2	1.83703704	0.91851852	1.23	0.2961
Feed	2	14.63703704	7.31851852	9.83	0.0001
Moisture	2	0.01481481	0.00740741	0.01	0.9901
Speed	4	13.58518519	3.39629630	4.56	0.0021
Feed*Moisture	4	2.38518519	0.59629630	0.80	0.5276
Feed*Speed	8	6.10370370	0.76296296	1.03	0.4234
Moisture*Speed	8	5.39259259	0.67407407	0.91	0.5156
Feed*Moisture*Speed	16	12.65185185	0.79074074	1.06	0.4026

3. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for TE

NOTE: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	0.744276

Number of Means	2	3
Critical Range	.3614	.3803

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Feed
A	98.3111	45	1
B	97.8222	45	2
B			
B	97.5111	45	3

4. Valuation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for TE

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05	
Error Degrees of Freedom	88	
Error Mean Square	0.744276	
Number of Means	2	3
Critical Range	.3614	.3803

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Moisture
A	97.8889	45	1
A			
A	97.8889	45	2
A			
A	97.8667	45	3

5. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for TE

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05			
Error Degrees of Freedom	88			
Error Mean Square	0.744276			
Number of Means	2	3	4	5
Critical Range	.4666	.4910	.5072	.5190

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Speed
A	98.4815	27	5
B	97.9259	27	4
B			
B	97.7037	27	1
B			
B	97.6667	27	3
B			
B	97.6296	27	2

Dependent Variable: CE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	46	0.31562963	0.00686151	2.64	<.0001
Error	88	0.22869185	0.00259877		
Corrected Total	134	0.54432148			

R-Square	Coeff Var	Root MSE	CE Mean
0.579859	5.330377	0.050978	0.956370

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Rep	2	0.05530815	0.02765407	10.64	<.0001
Feed	2	0.00362815	0.00181407	0.70	0.5003
Moisture	2	0.01446370	0.00723185	2.78	0.0673
Speed	4	0.04024741	0.01006185	3.87	0.0061
Feed*Moisture	4	0.03016296	0.00754074	2.90	0.0263
Feed*Speed	8	0.03757926	0.00469741	1.81	0.0862
Moisture*Speed	8	0.04403259	0.00550407	2.12	0.0422

Feed*Moisture*Speed	16	0.09020741	0.00563796	2.17	0.0117

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	0.05530815	0.02765407	10.64	<.0001
Feed	2	0.00362815	0.00181407	0.70	0.5003
Moisture	2	0.01446370	0.00723185	2.78	0.0673
Speed	4	0.04024741	0.01006185	3.87	0.0061
Feed*Moisture	4	0.03016296	0.00754074	2.90	0.0263
Feed*Speed	8	0.03757926	0.00469741	1.81	0.0862
Moisture*Speed	8	0.04403259	0.00550407	2.12	0.0422
Feed*Moisture*Speed	16	0.09020741	0.00563796	2.17	0.0117

6. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for CE

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	0.002599

Number of Means	2	3
Critical Range	.02136	.02247

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Feed
A	0.96089	45	2
A			
A	0.95911	45	3
A			
A	0.94911	45	1

7. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for CE

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	0.002599

Number of Means	2	3
Critical Range	.02136	.02247

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	Moisture
A		0.96933	45	3
A				
B	A	0.95578	45	1
B				
B		0.94400	45	2

8. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for CE

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	0.002599

Number of Means	2	3	4	5
Critical Range	.02757	.02901	.02997	.03067

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Speed
A	0.97556	27	5

A			
A	0.96963	27	4
A			
B A	0.96481	27	3
B			
B C	0.94037	27	1
C			
C	0.93148	27	2

The GLM Procedure

Dependent Variable: MGD

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	46	217.9111111	4.7371981	2.58	<.0001
Error	88	161.8222222	1.8388889		
Corrected Total	134	379.7333333			

R-Square	Coeff Var	Root MSE	MGD Mean
0.573853	1.482209	1.356056	91.48889

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Rep	2	13.51111111	6.75555556	3.67	0.0294
Feed	2	5.91111111	2.95555556	1.61	0.2063
Moisture	2	1.11111111	0.55555556	0.30	0.7400
Feed	4	73.43703704	18.35925926	9.98	<.0001
Feed*Moisture	4	59.37777778	14.84444444	8.07	<.0001
Feed*Speed	8	3.94074074	0.49259259	0.27	0.9747
Moisture*Speed	8	25.18518519	3.14814815	1.71	0.1067
Feed*Moisture*Speed	16	35.43703704	2.21481481	1.20	0.2809

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	13.51111111	6.75555556	3.67	0.0294
Feed	2	5.91111111	2.95555556	1.61	0.2063
Moisture	2	1.11111111	0.55555556	0.30	0.7400
Speed	4	73.43703704	18.35925926	9.98	<.0001
Feed*Moisture	4	59.37777778	14.84444444	8.07	<.0001
Feed*Speed	8	3.94074074	0.49259259	0.27	0.9747
Moisture*Speed	8	25.18518519	3.14814815	1.71	0.1067
Feed*Moisture*Speed	16	35.43703704	2.21481481	1.20	0.2809

9. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for MGD

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	1.838889

Number of Means	2	3
Critical Range	.5681	.5978

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Feed
A	91.7333	45	3
A			
A	91.5111	45	1
A			
A	91.2222	45	2

10. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for MGD

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	1.838889

Number of Means	2	3
Critical Range	.5681	.5978

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Moisture
A	91.6000	45	3
A			

A	91.4889	45	1
A			
A	91.3778	45	2

11. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for MGD

NOTE: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	1.838889

Number of Means	2	3	4	5
Critical Range	.7335	.7718	.7972	.8158

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Speed
A	92.6296	27	5
B	91.8148	27	4
B			
B	91.3333	27	3
B			
B	91.2963	27	2
C	90.3704	27	1

The GLM Procedure

Dependent Variable: SL

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	46	45.62519407	0.99185205	1.72	0.0147
Error	88	50.70472741	0.57619008		
Corrected Total	134	96.32992148			

R-Square	Coeff Var	Root MSE	SL Mean
0.473635	55.96346	0.759072	1.356370

Source	DF	Type I SS	Mean Square	F Value	Pr >
Rep	2	1.56153926	0.78076963	1.36	0.2633
Feed	2	9.88127259	4.94063630	8.57	0.0004
Moisture	2	2.47521037	1.23760519	2.15	0.1228
Speed	4	5.07869185	1.26967296	2.20	0.0751

Feed*Moisture	4	6.88962519	1.72240630	2.99	0.0230
Feed*Speed	8	7.14791259	0.89348907	1.55	0.1515
Moisture*Speed	8	2.73499704	0.34187463	0.59	0.7810
Feed*Moisture*Speed	16	9.85594519	0.61599657	1.07	0.3963

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	1.56153926	0.78076963	1.36	0.2633
Feed	2	9.88127259	4.94063630	8.57	0.0004
Moisture	2	2.47521037	1.23760519	2.15	0.1228
Speed	4	5.07869185	1.26967296	2.20	0.0751
Feed*Moisture	4	6.88962519	1.72240630	2.99	0.0230
Feed*Speed	8	7.14791259	0.89348907	1.55	0.1515
Moisture*Speed	8	2.73499704	0.34187463	0.59	0.7810
Feed*Moisture*Speed	16	9.85594519	0.61599657	1.07	0.3963

12. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for SL

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	0.57619

Number of Means	2	3
Critical Range	.3180	.3347

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Feed
A	1.6973	45	1
B	1.3362	45	2
B			
B	1.0356	45	3

13. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for SL

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha 0.05

Error Degrees of Freedom 88
Error Mean Square 0.57619

Number of Means	2	3
Critical Range	.3180	.3347

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	MOISTURE
A	1.5387	45	1
A			
A	1.3160	45	3
A			
A	1.2144	45	2

14. Evaluation of an Improved Soybean Thresher

The GLM Procedure
Duncan's Multiple Range Test for SL

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha 0.05
Error Degrees of Freedom 88
Error Mean Square 0.57619

Number of Means	2	3	4	5
Critical Range	.4106	.4320	.4463	.4567

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	Speed
	A	1.6126	27	5
	A			
B	A	1.4737	27	3
B	A			
B	A	1.4070	27	4
B	A			
B	A	1.2341	27	2
B				
B		1.0544	27	1

The GLM Procedure

Dependent Variable: TC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	46	1980.962963	43.064412	7.92	<.0001
Error	88	478.251852	5.434680		
Corrected Total	134	2459.214815			

R-Square	Coeff Var	Root MSE	TC Mean
0.805527	9.893663	2.331240	23.56296

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Rep	2	5.748148	2.874074	0.53	0.5911
Feed	2	1505.437037	752.718519	138.50	<.0001
Moisture	2	24.948148	12.474074	2.30	0.1067
Speed	4	196.251852	49.062963	9.03	<.0001
Feed*Moisture	4	74.696296	18.674074	3.44	0.0117
Feed*Speed	8	29.525926	3.690741	0.68	0.7087
Moisture*Speed	8	88.237037	11.029630	2.03	0.0519
Feed*Moisture*Speed	16	56.118519	3.507407	0.65	0.8380

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	5.748148	2.874074	0.53	0.5911
Feed	2	1505.437037	752.718519	138.50	<.0001
Moisture	2	24.948148	12.474074	2.30	0.1067
Speed	4	196.251852	49.062963	9.03	<.0001
Feed*Moisture	4	74.696296	18.674074	3.44	0.0117
Feed*Speed	8	29.525926	3.690741	0.68	0.7087
Moisture*Speed	8	88.237037	11.029630	2.03	0.0519
Feed*Moisture*Speed	16	56.118519	3.507407	0.65	0.8380

15. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for TC

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	5.43468

Number of Means	2	3
Critical Range	0.977	1.028

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Feed
A	27.6000	45	3
B	23.6667	45	2
C	19.4222	45	1

16. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for TC

Note: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	5.43468

Number of Means	2	3
Critical Range	0.977	1.028

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Moisture
A	23.8889	45	2
A			
A	23.8444	45	1
A			
A	22.9556	45	3

16. Evaluation of an Improved Soybean Thresher

The GLM Procedure

Duncan's Multiple Range Test for TC

NOTE: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	88
Error Mean Square	5.43468

Number of Means	2	3	4	5
Critical Range	1.261	1.327	1.371	1.403

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Speed
A	25.5556	27	5
A			
A	24.3333	27	4
B	22.8889	27	2
B			
B	22.7037	27	3
B			
B	22.3333	27	1

APPENDIX xi:

COST ESTIMATE FOR THE PRODUCTION OF THE SOYBEAN THRESHER

COMPONENTS	TYPES OF MATERIAL	QUANTITY	UNIT	TOTAL
Frame	Mild steel angle iron	4	3700	14800
Shafts for drum, shaker and fan	Mild steel 1.5	3	4100	12300
Bearings	Bearing 6250	8	580	4640
Pulleys	140mm 160 mm 320 mm	3	1200	3600
Bolt and nut	-	20	50	1000
Cutting disc	-	2	400	800
Feeding hopper and fan housing	Mild steel sheet gauge 18	3	4300	12,900
Bearing housing	3GI PIPE	5 feets	1500	1800
Fan Belts	-	3	350	1050
Beater rod	5/8 mild steel rod	2	2300	4600
Concave rod	10mm x 10mm square bar	10800mm length	2500	2500
Drum sheet	`3mm sheet metal	1	1500	1500
Miscellaneous	-	-	-	5000
Prime mover	-	1	40000	40000

TOTAL ₦106,490

PLATE. 1 Shows the side view of the thresher

PLATE. 2 Shows the threshing operation

PLATE. 2 SHOWS THE THRESHING OPERATION

PLATE. 3 Showing the back view of the thresher

Result of Performance Evaluation of the Soybean

Thresher

Variable Combination	Qu kg	Qo kg	Ql kg	Qb kg	Qs kg	Qt kg	We kg	Wt kg	T Sec	Threshing/ eff (%)	mechanical grain damage (%)
F1 M1 S1	0.0003	0.23	0.008	0.002	0.0238	0.241	0.03	0.26	59	99	0.8
F2 M1 S1	0.01	0.30	0.004	0.003	0.394	0.351	0.04	0.34	62	97	0.86
F3 M1 S1	0.011	0.381	0.0043	0.0038	0.385	0.435	0.051	0.432	65	97	0.89
F1 M1 S2	0.0003	0.33	0.0095	0.003	0.3395	0.343	0.02	0.35	56	99	0.88
F2 M1 S2	0.004	0.33	0.0026	0.0033	0.333	0.337	0.03	0.36	58	98	0.89
F3 M1 S2	0.012	0.43	0.004	0.0043	0.434	0.446	0.045	0.475	59	97	0.96
F1 M1 S3	0.002	0.26	0.007	0.0026	0.267	0.269	0.026	0.286	60	98	0.97
F2 M1 S3	0.01	0.347	0.003	0.0035	0.35	0.36	0.043	0.39	62	97	0.97
F3 M1 S3	0.013	0.43	0.005	0.0043	0.435	0.448	0.05	0.45	65	97	0.96
F1 M1 S4	0.0003	0.270	0.0024	0.0027	0.272	0.275	0.02	0.29	56	98	0.98
F2 M1 S4	0.01	0.330	0.0027	0.0033	0.333	0.343	0.04	0.370	58	97	0.96
F3 M1 S4	0.011	0.449	0.0029	0.0045	0.452	0.463	0.046	0.495	61	98	0.97
F1 M1 S5	0.0032	0.335	0.0024	0.0034	0.359	0.337	0.025	0.36	51	99	0.99
F2 M1 S5	0.01	0.425	0.0027	0.043	0.452	0.428	0.045	0.47	53	98	0.93
F3 M1 S5	0.012	0.51	0.097	0.005	0.58	0.59	0.054	0.564	58	98	0.85
F2 M2 S1	0.002	0.27	0.0021	0.0027	0.272	0.274	0.03	0.300	61	99	0.98
F2 M2 S1	0.01	0.498	0.025	0.005	0.52	0.53	0.046	0.49	63	98	0.94
F3 M2 S1	0.011	0.452	0.002	0.0045	0.472	0.454	0.048	0.5	62	99	0.93
F1 M2 S2	0.003	0.190	0.007	0.011	0.197	0.2	0.02	0.21	58	99	0.55
F2 M2 S2	0.004	0.338	0.002	0.0034	0.34	0.344	0.042	0.38	60	99	0.98
F3 M2 S2	0.014	0.44	0.004	0.004	0.483	0.444	0.056	0.499	62	97	0.81

Variable Combination	Qu kg	Qo kg	Ql kg	Qb kg	Qs kg	Qt kg	Wc kg	Wt kg	T Sec	Threshing/ eff (%)	mechanical grain damage (%)
F1 M2 S3	0.002	0.258	0.009	0.0026	0.267	0.269	0.022	0.280	55	99	0.97
F2 M2 S3	0.01	0.346	0.0021	0.0035	0.348	0.358	0.030	0.376	57	97	0.98
F3 M2 S3	0.013	0.462	0.004	0.0046	0.0466	0.479	0.038	0.500	60	97	0.83
F1 M2 S4	0.003	0.280	0.003	0.0028	0.283	0.286	0.030	0.310	54	98	0.96
F2 M2 S4	0.004	0.399	0.006	0.039	0.405	0.409	0.032	0.431	57	99	0.98
F3 M2 S4	0.012	0.463	0.095	0.046	0.468	0.48	0.035	0.498	59	98	0.95
F1 M2 S5	0.003	0.33	0.009	0.0033	0.339	0.342	0.03	0.360	52	99	0.97
F2 M2 S5	0.004	0.41	0.005	0.0041	0.415	0.419	0.042	0.45	54	99	0.98
F3 M2 S5	0.013	0.451	0.008	0.0045	0.459	0.472	0.041	0.492	57	97	0.95
F1 M3 S1	0.003	0.26	0.0031	0.0026	0.263	0.266	0.024	0.284	52	99	0.91
F2 M3 S1	0.004	0.33	0.0032	0.0033	0.333	0.337	0.035	0.365	28	99	0.98
F3 M3 S1	0.014	0.444	0.0035	0.0044	0.448	0.462	0.042	0.486	60	97	0.95
F1 M2 S2	0.003	0.268	0.006	0.0026	0.274	0.277	0.032	0.300	59	98	0.93
F2 M3 S2	0.01	0.357	0.0023	0.0035	0.359	0.369	0.037	0.394	60	97	0.94
F2 M2 S2	0.011	0.436	0.0017	0.0044	0.438	0.049	0.046	0.482	59	98	0.98
F1 M3 S3	0.002	0.278	0.0035	0.0028	0.282	0.284	0.02	0.298	60	99	0.98
F2 M3 S3	0.004	0.37	0.022	0.0037	0.392	0.396	0.04	0.41	62	99	0.93
F3 M3 S3	0.012	0.459	0.008	0.005	0.467	0.479	0.04	0.499	57	97	1.02
F1 M3 S4	0.003	0.366	0.01	0.0037	0.376	0.379	0.003	0.396	59	99	0.98
F2 M3 S4	0.01	0.395	0.006	0.004	0.404	0.414	0.042	0.44	62	97	0.97
F3 M3 S4	0.013	0.464	0.007	0.0046	0.471	0.484	0.035	0.499	57	97	0.95
					Qo+Q2	Qs+Qu		Wc+Qo			

Variable Combination	Qu kg	Qo kg	Ql kg	Qb kg	Qs kg	Qt kg	Wc kg	Wt kg	T Sec	Threshing/ eff (%)	mechanical grain damage (%)
F1 M3 S5	0.003	0.29	0.005	0.0029	0.295	0.298	0.03	0.32	50	99	0.97
F2 M3 S5	0.004	0.363	0.006	0.0036	0.369	0.373	0.035	0.398	56	98	0.96
F3 M3 S5	0.012	0.461	0.008	0.0046	0.469	0.481	0.037	0.498	58	98	0.95
			R2								
F1 M1 S1	0.002	0.329	0.017	0.0033	0.346	0.348	0.031	0.36	56	99	0.95
F2 M1 S1	0.01	0.363	0.0031	0.0036	0.395	0.405	0.037	0.40	58	98	0.88
F3 M1 S1	0.011	0.446	0.003	0.0045	0.476	0.487	0.64	0.486	60	96	0.92
F1 M1 S2	0.03	0.35	0.009	0.0036	0.359	0.362	0.030	0.380	55	97	0.99
F2 M1 S2	0.01	0.38	0.007	0.0038	0.387	0.397	0.034	0.414	56	97	0.96
F3 M1 S2	0.012	0.451	0.0032	0.0045	0.454	0.466	0.041	0.492	58	97	0.97
F1 M1 S3	0.003	0.184	0.0016	0.0018	0.186	0.189	0.02	0.024	54	98	0.95
F2 M1 S3	0.004	0.345	0.009	0.0034	0.354	0.358	0.036	0.381	57	99	0.94
F3 M1 S3	0.013	0.456	0.004	0.046	0.46	0.473	0.039	0.495	59	97	0.97
F1 M1 S4	0.002	0.273	0.0023	0.0027	0.275	0.277	0.024	0.297	53	99	0.98
F2 M1 S4	0.01	0.359	0.0027	0.0035	0.362	0.372	0.037	0.396	56	97	0.94
F3 M1 S4	0.012	0.467	0.004	0.0046	0.471	0.483	0.043	0.510	58	98	0.95
F1 M1 S5	0.003	0.27	0.003	0.0027	0.273	0.276	0.028	0.298	52	99	0.98
F2 M1 S5	0.004	0.399	0.003	0.0039	0.402	0.406	0.032	0.431	55	99	0.96
F3 M1 S5	0.011	0.453	0.0016	0.0045	0.455	0.466	0.045	0.498	56	98	0.97

					Qo+Q2	Qs+Qu		Wc+Qo			
Variable Combination	**Qu**	**Qo**	**Ql**	**Qb**	**Qs**	**Qt**	**Wc**	**Wt**	**T**	**Threshing/ eff**	**mechanical grain**

	kg	kg	kg	kg	kg	kg	kg	kg	Sec	(%)	damage (%)	(
F1 M2 S1	0.002	0.264	0.003	0.0026	0.267	0.269	0.025	0.289	57	99	0.97	
F2 M2 S1	0.004	0.333	0.0031	0.0033	0.336	0.34	0.30	0.363	56	98	0.97	
F3 M2 S1	0.011	0.454	0.004	0.0045	0.458	0.469	0.042	0.496	60	97	0.95	
F1 M2 S2	0.002	0.29	0.004	0.002	0.294	0.296	0.03	0.32	57	99	0.68	
F2 M2 S2	0.01	0.395	0.0035	0.0039	0.398	0.409	0.035	0430	54	98	0.95	
F3 M2 S2	0.013	0.46	0.0042	0.0046	0.464	0.477	0.04	0.500	61	97	0.96	
F1 M2 S3	0.003	0.278	0.008	0.0028	0.286	0.289	0.032	0.310	56	95	0.97	
F2 M2 S3	0.01	0.362	0.0028	0.0036	0.365	0.375	0.036	0.398	58	97	0.96	
F3 M2 S3	0.012	0.424	0.0035	0.0042	0.428	0.439	0.046	0.470	61	97	0.95	
F1 M2 S4	0.003	0.31	0.0029	0.003	0.313	0.316	0.04	0.35	52	99	0.94	
F2 M2 S4	0.004	0.359	0.0032	0.0036	0.362	0.366	0.031	0.39	56	98	0.98	
F3 M2 S4	0.014	0.454	0.006	0.0045	0.460	0.474	0.04	0.494	59	97	0.95	
F1 M2 S5	0.002	0.276	0.003	0.0028	279	0.281	0.02	0.296	54	99	0.99	
F2 M2 S5	0.003	0.347	0.004	0.0035	351	0.354	0.034	0.381	56	99	0.99	
F3 M2 S5	0.012	0.452	0.0033	0.045	0.045	0.467	0.035	0.487	60	97	0.96	
F2 M2 S1	0.003	0.265	0.0018	0.027	0.0027	0.269	0.022	0.287	54	98	0.9	
F2 M3 S1	0.01	0.351	0.0023	0.0035	0.0035	0.356	0.033	0.384	58	97	0.98	
F3 M3 S1	0.012	0.456	0.0016	0.0045	0.0045	0.469	0.042	0.498	63	97	0.96	
F1 M3 S2	0.002	0.268	0.005	0.0027	0.0027	0.275	0.023	0.291	52	99	0.98	
F2 M3 S2	0.004	0.36	0.009	0.0036	0.0036	0.373	0.037	0.397	59	98	0.97	
F3 M3 S2	0.011	0.438	0.0019	0.0044	0.0044	0.451	0.050	0.488	62	98	0.98	

					Qo+Ql	Qs+Qu		Wt+Qo				
Variable	**Qu**	**Qo**	**Ql**	**Qb**	**Qs**	**Qt**	**Wc**	**Wt**	**T**	**Threshing/**	**mechanical**	**(**
Combination										**eff**	**grain**	**(**

	kg	kg	kg	kg	kg	kg	kg	kg	Sec	(%)	damage (%)
F1 M3 S3	0.004	0.261	0.0025	0.0026	0.264	74	.031	0.291	54	96	0.97
F2 M3 S3	0.011	0.36	0.0038	0.0036	0.364	0.365	0.039	0.40'	58	97	0.98
F3 M3 S3	0.01	0.454	0.0036	0.0045	0.458	0.468	0.041	0.495	61	98	0.96
F1 M3 S4	0.003	0.276	0.0025	0.0028	0.279	0.282	0.034	0.31	54	99	0.99
F2 M3 S4	0.01	0.345	0.007	0.0035	0.352	0.362	0.025	0.370'	57	97	0.99
F3 M3 S4	0.014	0.469	0.009	0.0047	0.478	0.492	0.028	0.497	60	97	0.97
F1 M3 S5	0.002	0.256	0.003	0.0026	0.259	0.261	0.03	0.286	33	99	0.81
F2 M3 S5	0.012	0.367	0.006	0.0037	0.373	0.385	0.027	0.394	57	97	0.99
F3 M3 S5	0.015	0.470	0.008	0.0047	0.478	0.493	0.029	0.499	59	99	0.95
		R3									
F1 M1 S1	0.001	0.269	0.042	0.0027	0.273	0.274	0.032	0.301	56	99	0.98
F2 M1 S1	0.004	0.35	0.0038	0.0035	0.354	0.358	0.042	0.392	58	98	0.98
F3 M1 S1	0.005	0.443	0.0054	0.0045	0.448	0.453	0.039	0.482	68	96	0.99
F1 M1 S2	0.002	0.248	0.0050	0.0025	0.253	0.255	0.028	0.276	54	97	0.98
F2 M1 S2	0.011	0.356	0.0040	0.0036	0.360	0.371	0.033	0.389	56	97	0.97
F3 M1 S2	0.013	0.456	0.0042	0.0046	0.460	0.473	0.042	0.498	59	98	0.99
F1 M1 S3	0.003	0.26	0.005	0.0126	0.265	0.268	0.03	0.29	57	98	0.99
F2 M1 S3	0.004	0.38	0.007	0.0038	0.387	0.391	0.041	0.42	60	99	0.97
F3 M1 S3	0.011	0.457	0.006	0.0046	0.462	0.473	0.038	0.495	61	99	0.97

					Qo+Ql	Qs+Qu		Wt+Qo			
Variable	**Qu**	**Qo**	**Ql**	**Qb**	**Qs**	**Qt**	**Wc**	**Wt**	**T**	**Threshing/**	**mechanical**
Combination										**eff**	**grain**

	kg	kg	kg	kg	kg	kg	kg	kg	Sec	(%)	damage (%)
F1 M1 S4	0.003	0.285	0.0018	0.0029	0.287	0.289	0.025	**0.310'**	54	98	1.0'
F2 M1 S4	0.004	0.305	0.0026	0.0031	0.308	0.312	0.032	0.337	57	98	0.94
F3 M1 S4	0.012	0.459	0.0045	0.0046	0.464	0.476	0.041	0.500'	58	97	0.98
F1 M1 S5	0.005	0.243	0.006	0.0024	0.249	0.254	0.032	0.275	51	99	1.20'
F2 M1 S5	0.01	0.319	0.009	0.0032	0.328	0.338	0.031	0.350;	52	98	0.95
F3 M1 S5	0.014	0.433	0.008	0.0043	0.441	0.455	0.042	0.475	54	99	0.95
F1 M2 S1	0.003	0.275	0.007	0.0028	0.278	0.281	0.025	0.300'	56	97	0.93
F2 M2 S1	0.003	0.402	0.0019	0.0041	0.404	0.407	0.028	0.430'	57	98	0.94
F3 M2 S1	0.013	0.482	0.0032	0.0048	0.485	0.498	0.038	0.520'	60	97	0.96
F1 M2 S2	0.001	0.271	0.004	0.0027	0.275	0.276	0.020'	0.291	55	96	0.97
F2 M2 S2	0.01	0.441	0.0029	0.0041	0.444	0.454	0.031	0.472	56	97	0.96
F3 M2 S2	0.012	0.463	0.0031	0.0046	0.466	0.478	0.052	0.515	58	97	0.99
F1 M2 S3	0.002	0.272	0.0016	0.0027	0.274	0.276	75	0.298	58	99	0.98
F2 M2 S3	0.01	0.331	0.003	0.0033	0.334	0.344	0.034	0.465	60	96	0.96
F3 M2 S3	0.011	0.449	0.004	0.0045	0.453	0.464	0.036	0.485	61	98	0.98
F1 M2 S4	0.002	0.248	0.003	0.0025	0.251	0.253	0.028	0.276	54	99	0.98
F2 M2 S4	0.004	0.415	0.0044	0.0042	0,.419	0.423	0.035	0450'	58	98	0.97
F3 M2 S4	0.016	0.452	0.009	0.0045	0.461	0.477	0.042	0.494	60	97	0.99
F1 M2 S5	0.003	0.327	0.029	0.0033	0.356	0.359	0.033	0.360'	50	99	0.97
F2 M2 S5	0.0045	0.47	0.0033	0.0047	0.503	0.508	0.04	0.43	58	99	0.99
F3 M2 S5	0.012	0.471	0.0029	0.00471	0.474	0.486	0.039	0.510;	60	98	0.98

					Qo+Ql	Qs+Qu		Wt+Qo			
Variable	Qu	Qo	Ql	Qb	Qs	Qt	Wc	Wt	T	Threshing/	mechanical
Combination										eff	grain

	kg	kg	kg	kg	kg	kg	kg	kg	Sec	(%)	damage (%)
F1 M2 S1	0.002	0.263	0.0011	0.0026	0.264	0.266	0.032	0.295	54	96	0.94
F2 M2 S1	0.004	0.373	0.0028	0.004	0.004	0.379	0.037	0.410	58	98	**1.0**
F3 M3 S1	0.015	0.444	0.0035	0.0044	0.0044	0.463	0.042	0.486	64	96	0.95
F1 M3 S2	0.006	0.274	0.0018	0.0027	0.0027	0.282	0.023	0.297	52	97	0.96
F2 M3 S2	0.004	0.347	0.0019	0.0035	0.0035	0.353	0.034	0.381	59	98	0.99
F3 M3 S2	0.011	0.458	0.003	0.0046	0.0046	0.472	0.040	0.498	63	97	0.98
F1 M3 S3	0.003	0.290	0.0014	0.0029	0.0029	0.294	0.030	0320	54	98	0.99
F2 M3 S3	0.010	0.362	0.0015	0.0036	0.0036	0.374	0.037	0.399	56	97	0.98
F3 M3 S3	0.012	0.470	0.0034	0.0047	0.0047	0.485	0.04	0.510	62	99	0.97
F1 M3 S4	0.005	0.281	0.0012	0.0028	0.0028	0.287	0.020	0.301	52	98	0.99
F2 M3 S4	0.011	0.365	0.020	0.0037	0.0037	0.378	0.041	0.406	56	98	0.98
F3 M3 S4	0.013	0.463	0.004	0.0046	0.0046	0.480	0.036	0.499	60	99	0.96
F1 M3 S5	0.002	0.256	0.008	0.0026	0.0026	0.266	0.024	0.280	55	99	0.98
F2 M3 S5	0.009	0.361	0.009	0.0036	0.0036	0.379	0.031	0.392	59	98	0.97
F3 M3 S5	0.014	0.451	0.0015	0.0045	0.0045	0.467	0.045	0.496	62	99	1.2