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# PERFORMANCE EVALUATION OF A SORGHUM THRESHER FOR FUELING NEW CYCLES OF SUCCESS IN THE THRESHING OF SORGHUM CROPS IN NORTHERN NIGERIA

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**ABSTRACT**

In order to improve on the traditional method of threshing and cleaning of sorghum, a thresher was designed, constructed and its performance was evaluated in the Department of Agricultural Engineering, A.B.U Zaria. The result shows the threshing efficiency, cleaning efficiency, mechanical grain damage, throughput capacity and scatter loss of 99.8%, 98.7%, 5.09%, 110% and 11.4% respectively. The statistical analysis of variance on the result indicates that the independent variables; speed, moisture content and feed rate have a significant effect on the dependent variables; threshing efficiency, cleaning efficiency, throughput capacity and scatter loss at 0.05 probabilities level respectively.

**Keywords**; Sorghum, Thresher, Performance, Evaluation

## INTRODUCTION

A lot of work has been undertaken by a number of researchers on the threshing and the cleaning, right from the design, development and evaluation. All these investigations have in one way or the other contributed to the understanding of the threshing and cleaning processes of sorghum (Enaburekar, 1994) A sorghum thresher is mechanical thresher designed and constructed to separate the grains from the ear head. It has a threshing drum, which consists of a long cylindrical shape member to which a series of spikes, are attached on its surface. The threshing drum is mounted on two bearings and rotates in a perforated trough “concave”. During threshing, sorghum is fed between the threshing drum and the concave, where it is subjected to a high degree of impact and/or rubbing forces which detach grains from panicles **(**Amir, 1990). The mechanical cleaning of grain is done by thresher cum winnower, which consists of fan blade, which is enclosed by a casing and attached to the mechanical thresher. A fan is connected to the shaft and powered by an electric motor, thereby generating air current that blows a reciprocating sieve to drive off the chaff (Ajayi, 1994). Amir (1990) reported two types of threshers: as the beater type and the axial flow type. According to him, the beater thresher has a threshing cylinder which rotates in an enclosed chamber, with lower part of the chamber forming the concave. In the axial flow thresher, crop moves spirally between the threshing drum and a circular concave for several complete turns. In this thresher, almost all of the grains are separated from the straws through the concave perforation. Chaffs are finally ejected through a large straw outlet at one end of the concave.

Abiodun **(**2000) designed and developed a manually operated sorghum thresher which was constructed with local materials and tested based on the following parameters: the threshing rate and the threshing efficiency. The thresher had a drum with spirally arranged rasp bars, a concave, feed hopper welded on to the upper concave, a stationary screen with iron rods and a lever handle. It was observed that the performance evaluation test carried out on the machine gave a threshing rate of 72kg/h and 60% threshing efficiency.

Nalado (2006) carried out modification on the screen of maize thresher at the Institute of Agricultural Research, Ahmadu Bello University, Zaria to adapt the thresher for additional threshing of sorghum, millet, cowpea and groundnut respectively, the result revealed that for sorghum, the threshing efficiency, cleaning efficiency, mechanical grain damage, and throughput capacity values were; 99%, 93%, 1.70%, 230 kg/h, respectively at speed of 950 rpm, feed rate of 60 kg/h and 9% moisture content level.

Hunt (1983) observed that factors like moisture content, concave drum clearance, length of threshing drum and pitch of screw are factors that affect the threshing of sorghum on the threshing efficiency, cleaning efficiency, scatter loss, mechanical grain damage and throughput capacity while Kepner *et al*. (1992) noted that the efficiency of threshing depends on the peripheral speed of the cylinder, the clearance between the cylinder and the concave, the maturity of the crop and the rate at which the crop is fed into the machine. Simonyan *et al*. (2006) reported that the increase in moisture content may lead to more adhesiveness between the sorghum grains and other constituents to be separated, adding that increase in cylinder speed results in an increase in the range of particles size and formation of minute particles, which aerodynamically resembles sorghum grains, thereby creating challenges in the cleaning operation. Grochowicz (1980) reported that when the resident time (time which threshed material awaits separation or cleaning) is longer, it positively affects the efficiency of separation, as there is likelihood for lighter particles being displaced in the air stream. The specific objectives are to; design a sorghum thresher, construct the sorghum thresher using available local materials and to evaluate the performance of the thresher

## MATERIALS AND METHODS

**Design considerations;** The sorghum thresher was designed based on the following considerations:

i. The optimal cylinder speed of 700 rpm was used, because a speed above this has indicated more grain damage and increase losses (Nalado, 2006). Hence using this speed provides less scatter losses and grain damage.
ii. The factors considered in the design of the blower unit were the width and length of the blades, number of the blades and the weight of the blades, angle between blower and air discharge through the blower.
iii. The requirement of air discharge through the blower was estimated on the consideration of the velocity of the air required for cleaning, depth of air stream, width

over which air is required, length of blade and number of blades.

iv. The factors considered in the selection of pulley sizes were based on speed of the driven and drive pulley.

v. In the selection of belt length, the factors taken into consideration were the length, sizes of the belt, the speed and angle of contact of the belt on the pulley and thickness of the belt which depend on the speed ratio and the power to be transmitted.

vi. Determination of shaft diameter, length and material selection is very important in the design process, hence it transmit power under operation and loading conditions. It also involves material selection so that it is cheaply met.

vii. Allowable for shock and fatigue :ASAE (1948), recommended the value of bending moment($M_b$) and torque (T) action on the shaft be multiplied with combined shock and fatigue factors applied to torsion and bending moment ($K_t$ = 1.0 to 1.5, $K_m$ = 1.5 to 2.0), respectively.

viii. Using ASME (1948) code for steel which gives the steel allowable stress ($S_a$), the lesser value between both critical point chosen; 30% of the elastic limit and 18% of the ultimate strength while in tension for shaft without key way, that is 30% $S_x$ and 18% $S_y$.
Where: $S_x$ = stress at the critical point in tension.
$S_y$ = stress at the critical point in the direction normal to the $S_x$ stress which is further reduced by 25% when there is stress concentration on the shaft with key way.

ix. The thresher was operated using diesel engine, this is because of its easy variable speed selection, more available and cheaper to buy (Jibatswen, 2012)

**Selection of Materials**

Angle iron of size 250 x 3x 250 mm was chosen for the frame of the thresher because of its availability and cheapness and mild steel metal sheet of gauge 16 mm was selected for the sieve plate. Gauge 18 mm mild steel metal sheets was selected for the construction of hopper with its side tilted to achieve easy feeding of the product into the threshing unit. And mild steel (c1040) was selected for shaft based on the strength and the availability of the materials (Jibatswen, 2012).

**Design Theory and Calculation.**

The weight of the fan blades were estimated from the formula adapted from Hannah and Stephen (1984):

$W = \partial g v$---------------------------------------------------------1

Where: δ = density of fan blade material i.e. steel ( kg /m$^3$).
$g$ = acceleration due to gravity (9.81m/ s$^2$).
$v$ = volume of the fan blades (m$^3$) = length × height × thickness of blade.

The air discharge rates (Q) were estimated from the formula given by Joshi (1981):

$Q = VDW$.-----------------------------------------------------2

Where: Q = Air volumetric discharge rate (m $^3$/min).
V = air velocity (m/min). D = Diameter of fan (m).
W = Weight of fan blade (kg).Given that the fan speed is in (rpm).

The Pulleys were selected based on the speed ratio formula as recommended by Hannah and Stephen (1984):

$N_1D_1 = N_2D_2$ -------------------------------------------------3

Where: $N_1$ = Speed of drive (prime mover) rpm,
$D_1$ = diameter of drive pulley (mm),
$N_2$ = Speed of thresher pulley (rpm),
$D_2$ = diameter of thresher pulley (mm).

The Belt lengths were estimated using the relation given by Kepner *et al*. (1992) as shown below:

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

Where: L = effective length of belt (cm),
C = centre distance from drive to driven pulley (cm)
D = diameter of driven pulley (cm), d = outside diameter of drive pulley (cm)

The angle contact was adapted from Hannah and Stephen (1984) as shown below:

$\emptyset = 180 - \frac{(D-d)}{c} \times 60$---------------------------------------5

Where: Ø = angle of contact,
D = diameter of drive pulley (cm).
d = outside diameter of drive pulley (cm)

The Belt speed was estimated from equation of Hannah and Stephen (1984) as shown below:

$N = \frac{V}{\pi D}$ -------------------------------------------------------6

Where: N = drive speed (rpm),
V = Belt speed (m/s),
D = diameter of drive pulley (cm).

The Belt Tension was estimated as followed:

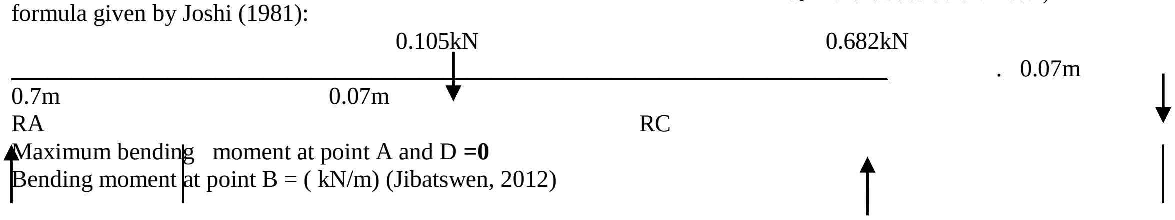
Total belt tension = $S_1 + S_2$ where ($s_1 + s_2$)r =T and $s_1$=3$s_2$ ---------------------------------7

Where: $S_1$ = tension on slide side (k N),
$S_2$ = tension on tight side (k N)
r = radius of pulley (m)
T = torque on shaft (k N/m)

The shaft diameter was obtained from the formula given by Hall and Hollowenko (1982):

$d_0{}^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$-------------------------------8

Where: $M_t$ = torsional moment (Nm),
$M_b$ = bending moment, (Nm)
$K_b$ = combined shock and fatigue factor applied to bending moment = 1.5
$K_t$ = combined shock and fatigue factor applied for torsional moment =1.0
$S_s$ = allowable stress for shaft with key way: (40N/m$^2$)
$d_0$ = shaft outside diameter, m




Maximum bending moment at point A and D **=0**
Bending moment at point B = ( kN/m) (Jibatswen, 2012)

**Experimental Designed**

A layout of 5 levels moisture (16%, 14%,12% ,10% and 8%), 5 levels cylinder speed ( 300, 400, 500, 600, and 700 rpm) Feed rate = (2 levels: 1 and 2 kg).

**Experimental Determinants**

i. Determination of design- related physical and mechanical properties of the sorghum.
ii. Determination of the effect of cylinder speed on the threshing of sorghum.
iii. Determination of the effect of moisture content on the threshing of sorghum
iv. Determination of the effect of feed rate on the threshing of sorghum.

**Performance Indicators.**

i. *Threshing efficiency.* This is defined as the quantity of threshed grain in sample to the total quantity in sample. The Threshing Efficiency were determined by using the formula given by Nderika (1994) as follows:

$$T_e = 100 - \frac{Q_u}{Q_t} \times 100 \quad \text{------------------------------------} \quad 9$$

Where: $T_e$ = threshing efficiency (%) ,

$Q_u$ = Quantity of unthreshed grain in a sample (kg)

$Q_t$ = total quantity of grain in sample (kg)

ii. *Cleaning efficiency*

$$C_e = \frac{(W_T - W_C)}{W_T} \times 100 \text{----------------------------------------} 10$$

Where: $C_e$ = cleaning efficiency (%) ,

$W_T$ = Total mixture of grain and chaff received at the main outlet (kg)

Wc = weight of chaff at the main outlet of thresher (kg) Nderika, (1994**).**

**Instrumentation**

i. Time; The time for the crops feeding in second was measured with a digital stop watch.

ii. Shaft speed; in order to determine the speed of the cylinder shaft, a tachometer was used.

iii. Feed rate; the estimated feed rate was computed by a weighing balance as weight of crop fed in to the machine per unit time in second.

**Data Analysis**

The effect of the variable parameter on the performance indicator was compared using graphical methods and statistical tools. The analysis of variance (ANOVA) for the layout was calculated via degree of freedom (DF) the sum of square (SS) and the mean square value. The F calculated was compared with F- tabulated to determine the level of significant between the dependent and independent variables.

**Construction of the Thresher**

**The hopper** ; the hopper was constructed from a mild steel metal sheet gauge 18. The metal sheet protrudes from the top cylinder with the width is 32cm,the base width 30cm and height 32cm.

**The threshing unit**: this is where the threshing of the grain occurs. In this unit the threshing of sorghum is mainly by, impact and rubbing, the action happened by the beater simultaneously. The continue action of the beater forces the grains to be detached from the ear head. Both the grains and the chaffs pass on to the shaker through the concave opening. This unit consists of the beater assembly, perforated concave plate, and top cylinder.

i *Beater assembly***.** The threshing drum consists of a long galvanized cylindrical metal pipe 71cm long through which the shaft passes. A series of spikes tooth are attached on this galvanized pipe which is mounted on two bearings and rotates, which beat the sorghum ear head against the concave thereby resulting to the threshing of the grains. The spacing between beaters was 11cm and the lengths of the spikes were 6cm in height with 42 numbers of spikes tooth in total.

ii *Top cylinder cover***.** The top cylinder cover was constructed from mild steel metal sheet gauge 18 which was chosen based on its durability and strength. It was used to cover or case the beater assembly, as well as having the hopper fixed to it. The metal sheet was dimensioned as 36 cm, based on the design requirement and rolled into a cylindrical shape with the hopper protruding from that point.

iii *Perforated Concave Plate***.** This part is stationary and is located between the beaters assemblies with clearance of 0.7cm to the beater. Some time it is adjustable in relation to the beater assembly. It was constructed from a metal rod with a diameter of 3.5cm and 68cm in length. The rods are braced together at equal interval to each other so as to enhance smooth passage of threshed materials.

**The blower:** the axial flow centrifugal fan was used as a blower. The impeller carries four blades whose height were 13.5cm, with the base welded to the shaft. It was made from gauge 18 metal sheets and was set at angle of $90^0$ to the impeller.

**The shaker and sieve:** the thresher was provided with a shaker situated on the frame. It was made from mild steel gauge 16 thicknesses. The shaker reciprocates via a crank shaft connected to it through a connecting rod. It also acts as a grain collecting point which conveys grains to the grain delivery unit as is tilted at an adjustable angle. The shaker carries the sieve for the cleaning of the grains. It consists of a tray located below the threshing cylinder and the fan which receives the threshed materials by the reciprocation movement. The sieve plate was constructed from mild steel metal gauge 18 with rectangular holes bored on it at 2mm interval and dimensioned as 72cm by 84cm so that the grain can pass through on to the shaker. The sieve is positioned inside the shaker.

**The supporting frame:** the frame of the thresher was constructed using 36×36×3 mm angle iron. It has a dimension of 100cm in length, 111cm in height and 83cm in width. The supporting frame has in all two extensions, one of which is at the top and houses the threshing unit, while the middle extension houses the fan or blower.

**Pulleys:** At the end of the cylinder shaft, two pulleys of 14 and 17 cm in diameters were mounted, while the blower shaft has one pulley of diameter 14 cm while shaker shaft has one pulley of diameter 17 cm. All of these pulleys were made of cast iron.

**Fan and fan housing:** the threshing blower or fan consists of four blades made of mild steel metal sheet gauge 16 fixed on galvanized metal pipe with the assistance of metallic flat bar welded to the pipe. While the fan housing was made from metal sheet of 4.50 cm and with the extension to the shaker through which air was delivered to clean the threshed grains.

**The shaft**: The shafts were selected based on their strength and durability. There were three shafts on the thresher, the shaft for the cylinder, fan and that of the shake, respectively. All these shafts were made from mild steel rod. Their individual lengths were 73, 76 and 75 cm, respectively ( Jibatswen, 2012)

**The Working Principle of the Thresher**

The sorghum thresher was designed and constructed to separate the grains from the stalk or chaffs. It has a threshing drum, which consists of a long cylindrical shape member to which a series of spikes, are attached on its surface. The threshing drum is mounted on two bearings and rotates in a perforated trough or concave. During threshing, crop is fed through an opened hopper which moved between the threshing drum and the concave, where it is subjected to a high degree impact and frictional forces which detach grains from panicles**.** The mechanical cleaning of grain is done by the thresher and winnower. The thresher cum winnower consists of fan blade, which is enclosed by a casing and attached to the mechanical thresher. This fan is connected to the shaft, powered by a prime mover, which helps to rotate the fan blade to generate the air current that blows a reciprocating sieve to drive the chaff and allows the grains to be collected at the grains pan (Jibatswen, 2012).

**RESULTS AND DISCUSSION.**

**The Effect of Cylinder Speed on the Threshing Efficiency**

The Threshing Efficiency was determined by using the formula given by Nderika, (1994)

$$T_e = 100 - \frac{Q_u}{Q_t} \times 100 \qquad 9$$

Where: $T_e$ = threshing efficiency (%) ,

$Q_u$ = Quantity of un threshed grain in a sample (kg)

$Q_t$ = total quantity of grain in sample (kg)

Figure 1 below, indicates that the lower threshing efficiency of 93.3% was obtained at the low cylinder speed of 300 rpm at 16% moisture content level wet basis and 2kg/s feed rate. This is in conformity with (Kabede and Mishra, 1990) report, who recorded a lower threshing efficiency of 98.3% at the cylinder speed of 300rpm and feed rate of 10 kg/min. The higher threshing efficiency of 99.7% was obtained at the cylinder speed of 700 rpm and moisture content of 9% level when the feed rate was 1 kg/s in all the replications. The reason for the low threshing efficiency at low cylinder speed could be associated with the fact that as the speed decreased the number of times the beater spikes pass through a point per unit time decreases (Jibatswen, 2012). Figure 1 showed that as the threshing efficiency's increased with decrease in the feed rate, because the sorghum ear heads in the threshing chamber interact with all the spikes such that there is a higher opportunity for detachment to occur (Enaburekan, 1994). This is similar to the report of (Agunsoye, 2007) who recorded a threshing efficiency of 66% at the feed rate of 44 kg/min and 73.3% at the feed rate of 1 kg/min. As seen in Figure .1 below, the $R^2$ values for the effect of the speed on the threshing efficiency at different feed rate and moisture content level are 0.893 and 0.970.

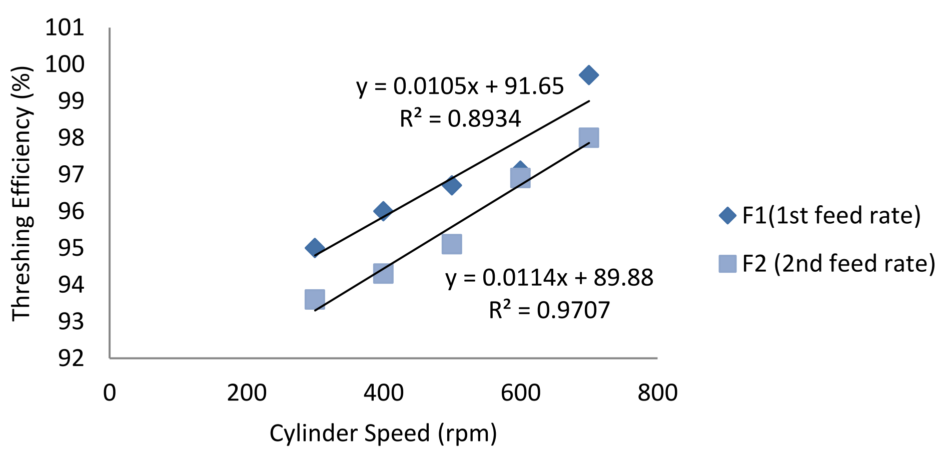



**Figure 1. The impart of cylinder speed on the threshing efficiency at two feed rates**

**The Effect of Moisture Content on the Threshing Efficiency**

Figure.2. revealed that the higher threshing efficiency of 99.7% was at the lower moisture content of 9% wet basis, cylinder speed of 700rpm and feed rate of 1kg/s in all levels (Jibatswen , 2012) which agreed with Duchy (1986), indicating that threshing efficiency increased with decrease in the moisture content level. The reason may be due to the fact that as the sorghum ear head reduced in moisture content, the impact of the spikes on the dried sorghum earhead creates grain detachment hence, promote high threshing efficiency while the lower threshing efficiency of 93.6% was obtained at the moisture content of 16% wet basis and feed rate of 2kg/s. The $R^2$ value were obtained to be 0.897 and 0.943 which indicates that as the moisture content increases the threshing efficiency reduces, while when the moisture content reduces the threshing efficiency increases.

**The Effect of Cylinder Speed on the Cleaning Efficiency**

Figure 3 shows that the cleaning efficiency of 99.3% was obtained at the cylinder speed of 700 rpm, moisture level of 9.0% wet basis and feed rate of 1 kg/s. The direction of the blower with high air velocity on the threshed material and the reciprocation of the shaker also assisted the separation of the grains from the chaffs thereby increasing the cleaning efficiency. While low cleaning efficiency of 71.2% was recorded at the low speed of 300rpm and moisture content of 16% (Jibatswen, 2012). This shows that low cylinder speed affects the cleaning efficiency. Figure 3. below still shows the high cleaning efficiency of 99.3% at feed rate of 1kg/s showing that less feed rate increased the cleaning efficiency. While the lower cleaning efficiency of 76.4% was at the feed rate of 2kg/s, meaning as the feed rate increased the quantities of threshed material needing cleaning also increased, thereby over burdening the cleaning unit at a particular time, hence reducing the cleaning efficiency. The $R^2$ value obtained were 0.954 and 0.973 which shows that as the speed of the machine increased from 300rpm to 700rpm, the cleaning efficiency also increases from 71.0% .to 76.4%.

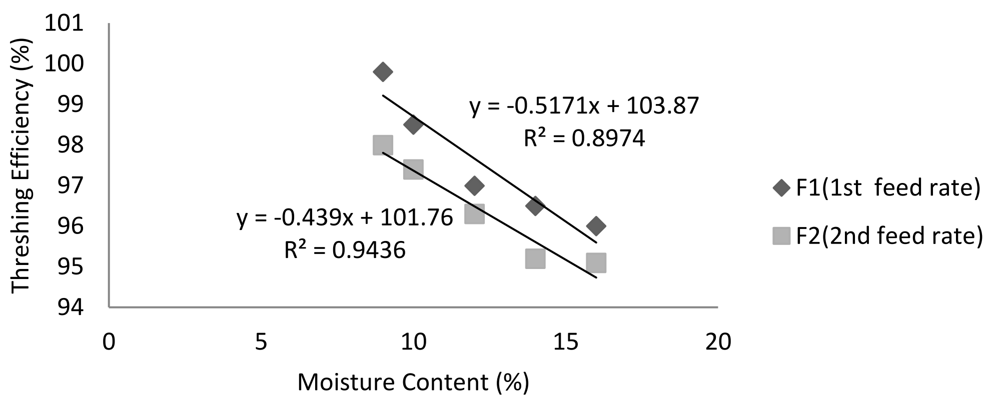



**Figure 2. The impart of moisture content on the threshing efficiency at two feed rates**

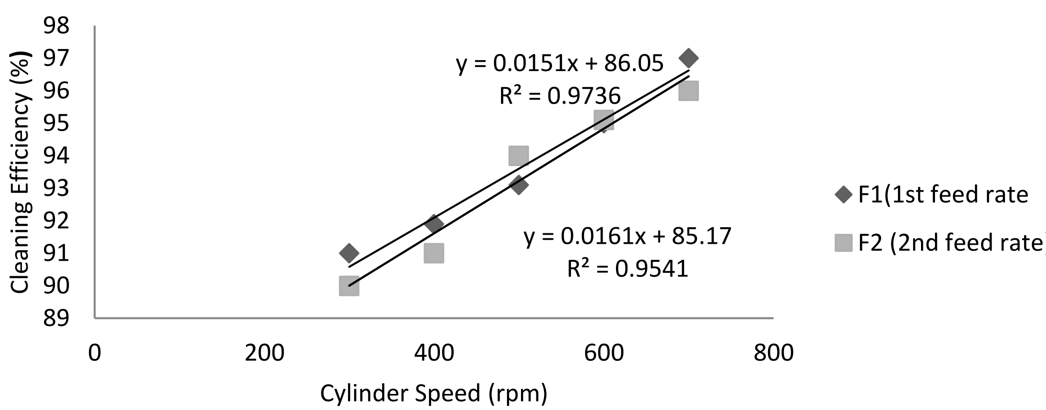



**Figure .3. Impart of cylinder speed on the cleaning efficiency at two feed rate**

**The Effect of Moisture Content on the Cleaning Efficiency**

Figure 4 below shows the effect of the moisture content on the cleaning efficiency at different feed rate and speed. The cleaning efficiency increased with decrease in the moisture content (Yavini, 2002). The higher cleaning efficiency of 99.6% was obtained at the moisture content of 9% wet basis. The reason for the high cleaning efficiency at low moisture content could be due to the dryness of the threshed materials whose constitutes can be easily separated from each other. The lower cleaning efficiency of 93.6% was obtained at the moisture content of 16% wet basis in all the replications, indicating that the higher the moisture, the lower the cleaning efficiency due to the difficulty of the sieve to separate the chaffs from the grains as a result of the dampness of the threshed materials. The $R^2$ values are 0.970 and 0.991; meaning that as the moisture content increases the cleaning efficiency reduces and when it reduces the cleaning efficiency increases.

In the Table 1 below, the result generally shows that increase in feed rate was not statistically significant to threshing efficiency at 0.05 probability level while the changed in the moisture content was statistically significant at 0.01 probability level. Likewise the speed was also significant at 0.05 probability level.

**The analysis of variance on the cleaning efficiency**

Table 1 shows the effect of speed, moisture, and feed rate are significance at 0.05% probability level, indicating that a change in the moisture content of the grain, speed of the machine and feed rate whether an increase or a decrease affect the cleaning efficiency.

**Table 1. The Analysis of Variance for the Threshing Efficiency**

| Source | DF | TE (F. values) | CE (F. values) |
|---|---|---|---|
| Rep | 2 | 12.03* | 17.22* |
| Feed | 1 | 2.18ns | 81.25ns |
| Moisture | 4 | 50.53* | 16.69* |
| Speed | 4 | 8.34* | 2.57* |
| Feed x Moisture | 4 | 3.64ns | 30.44ns |
| Feed x Speed | 4 | 0.68ns | 0.64ns |
| Moisture x Speed | 16 | 0.87ns | 0.64ns |
| Feed x Moisture x Speed | 16 | 0.96ns | 0.35ns |
| Error | 98 | | |
| Total | 149 | | |

*significant at 5%. ns: non significant at 5%

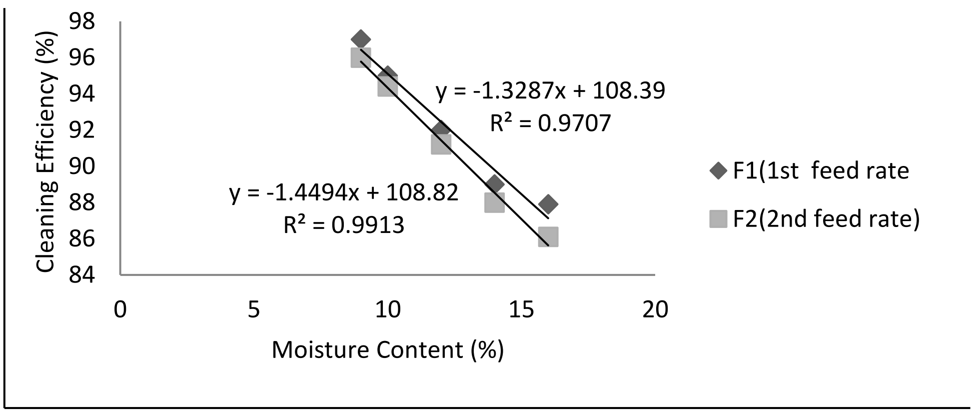



**Figure 4. The impart of moisture content on the cleaning efficiency at two feed rate**

**CONCLUSION**

The result of the performance evaluation shows a general increased in the threshing efficiency, cleaning efficiency, throughput capacity and a reduction in the mechanical grain damage as well as scatter loss

**RECOMMENDATIONS**

I wish to recommend the following:

i. The shaker should be fixed with two upper and lower sieves so as to enhance first and second cleaning that will be more efficient.
ii. The spikes in the threshing chamber should chisel to a knife like forms, so as to increase the cutting and impact effect on the sorghum ear heads.
iii. The hopper size should be increased so as to increase the quantity of the feed rate per hour; this will promote increase in throughput capacity.
iv. Peasant Farmers should be encouraged to buy or hire the thresher from Agricultural Engineering in order to reduce threshing drudgery and fatigue on their farms

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