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DEVELOPMENT OF A MANUALLY OPERATED LOW COST REEL LAWN MOWER

***Ogbeide, O.O. and Omatsola, O.S.**

Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City, Nigeria
*osarobo.ogbeide@uniben.edu

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ABSTRACT

A manually operated lawn mower was designed and fabricated to help in the development and maintenance of institution, community and the society in the area of grass cutting. During the design and construction of this machine, factors that were considered included environmental conditions, effectiveness of the machine and maintenance. The mower was designed with an internal spur and pinion gear system which transmits the torque to its spiral mechanism. The cutting mechanism was made of a flat blade rigidly fixed to the frame behind the reel arrangement which was configured to make a slight contact with the reel blades during its rotation. Test and performance evaluation of the machine was conducted at an open grass field in the premises of the University of Benin. An effective field capacity of 0.20 m^2/s and field efficiency of 63.44% was obtained. The cutting effectiveness was achieved at a rotary speed of 715 rpm of the shaft. The cost of this machine indicates that it is economically viable and is comparable to other currently available options in terms of efficiency.

1. INTRODUCTION

One of the basic requirements of modern man is his shelter. Man has constantly tried to adapt to his environment/surrounding by creating a habitat suitable for his survival. The natural environment which man lives in is usually covered with vegetation which includes forest trees or grasses. As man evolved intellectually, much effort has and will continue to be placed on improving the state/condition of his habitat for various purposes (security or aesthetic value). For man to build a shelter, he must reshape this virgin environment to his needs.

One of the ways man reshapes his environment is by cutting off the surrounding grasses. In the past, cutting of grasses was done by cutlasses, hoes or machetes which are usually time consuming, as it requires human effort, inaccuracy in cutting level and also a very high risk of accident when using this manual cutting methods. The need to overcome these setbacks was the motivation to develop a concept of a manually operated lawn mower. A lawn mower is a machine that uses one or more revolving blades to clear a grass surface to an even height. The blades may be powered either by hand, by pushing the mower forward to operate the mechanical blades, by an electric motor, or a small internal combustion engine to spin the blades. Some mowers also carry out other functions, such as mulching the cut grass or collecting their clippings in a bag. Two main styles of blades are used in lawn mowers. Lawn mowers employing a single blade that rotates about a single vertical axis are known as rotary mowers, while those employing a multiple blade assembly that rotates about a single horizontal axis are known as cylinder or reel mowers.

There are several types of mowers, each suited to a particular scale and purpose. The smallest types are pushed by a human user and are suitable for small residential lawns and gardens. Electrical or gas-engine-powered mowers are used for larger residential lawns. Riding mowers, which resembles small tractors, are larger than push mowers and are suitable for large lawns.

Pratik et al. (2014) designed and implemented an automatic lawn cutter that would cut the grass in their lawn with less effort. In their research, the different sensors been used would detect and avoid objects and humans while mowing. The main objective of their automatic lawn cutter was that the user could specify the area to be mown and also, the height of grass as per their requirement by using the keypad. Their design comprised of a microcontroller like AT mega 16, multiple sensors, LCD Display and keypad. The automatic lawn cutter was proven successful since its capacity was adequate for its purpose, and it could replace for the gasoline powered lawn mowers. Sivarao et al. (2010) researched on a conceptual design towards developing mechanically controlled semi-automated grass cutter, in which automatic control for grass cutting vehicle was required in order to cope with the environmental effect such as heat and rain, as well as strain on the driver. The driver of grass cutting vehicle or tractor has to operate and supervise the controlled and non-controlled implements along with vehicle guidance. Steering is a monotonous activity and tiring, which can result in reduced operation time and improve grass cutting quality. The need to overcome these setbacks was the motivation to develop a concept of a semi-automated steering guidance system for lawn tractors. Their paper presented the design conceptualizations of a mechanism to semi-automate a grass cutting tractor. Several conceptual designs were generated and proposed for the mechanism to be equipped with the tractor for it to self-propel semi-automatically. The scope of their concepts was for the tractor to travel in a spiral pattern on a flat terrain at constant moving speeds, and without external remote controlling devices. The actual development of the mechanisms to semi-automate the tractor for real life and economical application, was then embarked on. Harbhinder and Jaswinder (2015) designed and analyzed a wireless remote-controlled lawn mower. In their paper work, efforts were made to modify the old mower to improve its usability. An all new design was made and analyzed using

ANSYS. Their overall geometry was made smaller and lighter. Adjustable cutting motor height was introduced for better mowing of grass at intricate locations. The design was efficient and environmental friendly. Venkatesh et al. (2015) fabricated and analyzed a lawn mower, for the use of agricultural field, to cut the crops in the field. Their paper work presented a simple construction with an easy working principle. The components that were used are motor, gear arrangement, cam, lead screw, wheel, control unit and chain and sprocket. In their design work, the cutting blade was fixed below the gear arrangement, and when the motor was engaged to start running through the effects of power supply, the shaft also rotated, which in turn rotated the gear arrangement which was coupled with the motor. As the gear arrangement rotated the cam, it operates the sickle bar which then tends to cut the plant or crops. The entire set up was placed on a movable base which had a wheel arrangement. Their research work was a success with the hope that it was very much economical and helpful to many agricultural areas. Pamujula and Bhaskar (2015) developed a manually operated lawn mower to clean the lawn. Their rotary mower had a set of three wheels, one front wheel and two rear wheels. The shaft between the two rear wheels was connected to the compound gear train system. The wheels were rotated in forward motion and a bevel gear system, converted the forward motion to the vertical motion. The bevel gear system was connected to the blade and the blade was a low lift blade used for low speed. The manually operated rotary lawn mower was used to minimize the cost and power requirement for domestic purpose.

This paper presents the design and fabrication of a reel lawn mower suited for used in Nigeria. The problems of the manual cutting methods sighted above was meant to be overcome with the aid of this project (design and fabrication of a non-mechanized reel lawn mower) which is used for speedy cutting of grasses to equal height and level. This project work of designing a manually operated lawn mower tends to address some issues such as the availability and affordability of fossil fuels in Nigeria. Most importantly, it eliminates the emissions of carbon monoxides which are mostly responsible for environmental pollution and also causes *the green house effect* believed to be responsible for the worsening global warming of our planet. This paper aim is to show that a non-mechanized reel lawn mower is a pollution free, cheap and efficient machine that can serve as perfect alternative to the fuel driven lawn mowers.

2. METHODOLOGY

2.1. Design Analysis and Material Selection

The non-mechanized reel lawn mower with an adjustable handle consists essentially of the following components:

The Reel: It consists of several helixes shaped blades, welded to supports and mounted to a rotating shaft. This element is then ground to be a perfect cylinder.

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Bed knife/Stationary Blade: The bed-knife is fixed to the machine frame behind the reel. The bed knife is sharpened to be flat and square so the sharp edge contacts the reel blades across their entire length.

The Gears: The gear train consists of a driving internal spur gears fixed to each of the front wheels internally which transmits the torque from the wheels to the reel through the pinions on the shaft.

Driving wheels: The driving wheels propel the mower in action. The reel mower usually has two (2) main driving wheels and two (2) rear wheels.

Adjustable handle: The handle is made of a cylinder steel pipe which is folded toward the machine frame at an angle of 60^{o} which is adjustable for the operator's convenience.

The main frame: It is the main structural or body frame of the mower onto which the other parts of the mower are mounted. It also serves as a rigid support to other parts of the mower.

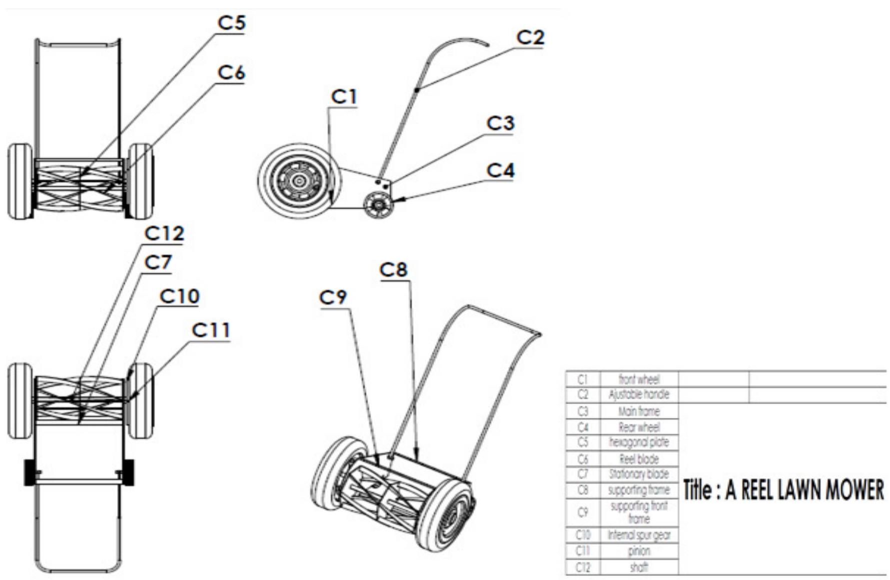

Figure 1: orthographic view of the reel lawn mower

3. DESIGN ANALYSIS

The following were chosen as the design standards. Average forward speed of the Machine (0.8m/s), width of cut (0.4 m), number of helical blades (n) (6), length of bedknife (402 mm), number of main gear teeth (83), number of pinion teeth (15), length of the cylinder (402 mm), radius of cylinder (67 mm). These specifications were chosen for operational convenience (Kepner et al., 1980).

The following components of the reel lawn mower were considered and designed:

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3.1. Determination of the Driving System

The angular velocity of the reel (a cylinder comprising of the helical blades and shaft) is obtained by converting the translational velocity at which the manual reel mower is pushed to the rotational velocity of the wheel. This is calculated by replicating the mowing speed and determining the time it takes to travel 6 meters. Table1 shows the result obtained in determining the mowing speed.

Table1: Time measurements for 6 meters of mower travel

Measurement	Time (s)
1	4.85
2	4.50
3	4.70
4	4.60
5	4.54
6	4.62
7	4.59
8	5.03
9	4.80
$t_{average}$ = 4.69secs	

Typical operator walking speed was determined using the average time to walk 6 meters with the following calculation:

$t_{average} = 4.69\ secs$
$d = 6meters$
$Operator's\ walking\ speed\ (V_{walk}) = {}^{distance}/_{time\ taken} = {}^{6}/_{4.69} = 1.3m/s$
$Diameter\ of\ main\ wheel (D_{wheel}) = 300mm \sim 0.3m$
$Circumference\ of\ wheel\ (C_{wheel}) = \pi \times D_{wheel}$
$C_{wheel} = \pi \times 0.3 = 0.94m$

$$angular\ velocity\ of\ wheel\ (\omega_{wheel}) = \frac{translational\ velocity\ of\ wheel\ (V_{wheel})}{C_{wheel}}$$

$$\omega_{wheel} = \frac{1.3}{0.94} = 1.383rad/s$$

$$\omega = \frac{2\pi N_{wheel}}{60}$$

$$N_{wheel} = \frac{60 \times 1.383}{2\pi} = 130rpm$$

The torque is transmitted to the reel by a gear system arrangement called a gear train. The gear ratio is:

$$Gear\ ratio = \frac{Teeth\ of\ Driving\ gear(T_1)}{Teeth\ of\ Driven\ gear(T_2)} = \frac{N_{reel}}{N_{wheel}} = \frac{83}{15} = 5.5 : 1$$

$$N_{reel} = N_{pinion} = N_{Shaft} = 5.5 \times 130 = 715rpm$$

$$\omega_{reel} = \omega_{pinion} = \frac{715}{60} = 11.92rad/s$$

3.2. Determination of Blade Angle

The helix angle, i for a cylinder having n partial helix is (Atkins, 2009):

$$\text{cotangent i} = \frac{\text{nW}}{2\pi \text{r}} \quad (1)$$

$$coti = \frac{6\times402}{2\times\pi\times67} = 5.73$$

$$i = 10°$$

Where $n = 6$

$W = 402mm$

$r = 67mm$

Slice/push *ratio*

$$\mathcal{E} = \frac{Ncos^2i - sin^2i}{(N+1)\,sin\,i\;cos\,i} \quad (2)$$

$$N = \frac{r\omega}{f} \quad (3)$$

$$= \frac{0.067\times11.92}{0.8}$$

$$N = 0.99$$

$$\therefore\ \varepsilon = \frac{0.99\ cos^2 10 - sin10}{(1.99)(sin10\ cos10)}$$

$$\varepsilon = 2.7$$

Where N= gearing of the cylinder with respect to the forward speed of the machine

W=length of the cylinder

f= machine moving velocity

ω=angular velocity

r=radius of the cylinder

The total cutting force per unit length of the cylinder is given by the relationship (Atkins, 2009):

$$\frac{\text{F}}{\text{R}_\text{w}} = \left[\left(\frac{1}{\sqrt{1+\varepsilon^2}}\right) + \text{S}\right] \quad (4)$$

$$\frac{\text{F}}{\text{R}_\text{w}} = [(\frac{1}{\sqrt{1+2.7^2}})+\text{S}]$$

$$\frac{\text{F}}{\text{R}_\text{w}} = [0.35 + \text{S}]$$

For n= 6 about 2 edges cut at any one time, so the total normalized force (F) is $2(0.35 + \text{S})$.

Where F=total cutting force

R_w=edges in contact with bedknife

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Ɛ=Slice/push ratio
S=frictional force between cutting blade and grass

3.3. Determination of Shaft Diameter

The shaft is subjected to both bending and torsional stresses. To obtain the maximum bending moment of the shaft, a free body and bending moment diagram was drawn (shown in Figure 2).

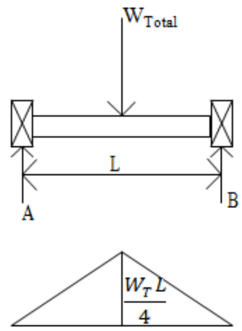

Figure 2: Free body and Bending Moment Diagram

The speed of shaft obtained is about 715 rpm. The maximum shear stress for shaft with allowance for keyways is 42MPa. To obtain the bending moment of the shaft, a free body diagram (Figure 2) showing forces acting on the shaft is drawn. Note, the shaft is supported by bearings at both ends while W_{Total} is the total weight acting on the shaft. Maximum bending moment occurs at the mid-span of the shaft.

3.4. Mass of the Cylinder

3.4.1. Mass of the helical blade

The reel is made up of six helix blades of size 402mm x 25mm x2mm

$Density\ of\ mild\ steel\ =\ 7850kg/m^3$, Number of helical blade, n = 6

$\rho = \frac{mass}{volume}$

But:

$$Volume\ =\ l\ x\ h\ x\ w\ (of\ the\ helical\ blade) \quad (5)$$

$= 0.402 \times 0.025 \times 0.002$
$= 2.01 \times 10^{-5} m^3$
Therefore, $mass = Density\ \times Volume$
$= 7850\ \times 2.01 \times\ 10^{-5}$
$m_h = 0.157785kg$

Total mass of helical blade,
$m_h = 6 \times 0.157785$ kg
$= 0.94671kg$

3.4.2. Mass of the circular spider

The blades are mounted on three spiders rigidly fixed to the shaft
$Radius\ of\ spider, r = 55mm$, Number of spiders, n = 3, $Thickness\ of\ spider, t = 2mm$
From volume of a cylinder:

$$v = \pi r^2 t \tag{6}$$

$v = 0.55^2 \times 0.002 \times \pi$
$v = 1.9 \times 10^{-5} m^3$
Therefore, $m = density \times volume$
$= 7850 \times 1.9 \times 10^{-5}$
$m = 0.149kg$
Total mass of spider,
$m = 3 \times 0.149$
$m_s = 0.447kg$
total mass of the cylinder:

$$m_T = m_h + m_s \tag{7}$$

And total weight, $W_T = (m_h \times 9.81) + (m_s \times 9.81)$
$= (0.94671 \times 9.81) + (0.447 \times 9.81)$
$= 9.287 + 4.39$
$W_T = 13.677N$
$W_T \sim 14N$
Therefore, maximum bending moment from Equation 8 (Hall et al, 1980):

$$M = \frac{W_T L}{4} \tag{8}$$

$$M = \frac{14 \times 0.402}{4}$$

$$M = 1.41Nm$$

Where W_T= total weight on shaft
L=length of shaft

The shearing force (F) of most annual and perennial grasses found on most lawns is usually between 9.2N ~ 11.51N. Torque required by the cutting blade to shear grass is (Khurmi, 2003):

$$T = F \times r \tag{9}$$

$$T = 11.51 \times 0.067$$

$$T = 0.77Nm$$

Where T= Shaft torque
r= Radius of the cylinder

The equivalent twisting moment (M_E) when acting alone produces the same shear stress as the actual twisting moment (Shigley, 2001).

$$M_E = \sqrt{M^2 + T^2} \tag{10}$$

$$M_E = \sqrt{1.41^2 + 0.77^2}$$
$$M_E = 1.4\,Nm$$

The equivalent bending moment (M_{Equ}) is taken as:

$$M_{Equ} = \frac{1}{2}(M + M_E) \qquad (11)$$

$$M_{Equ} = \frac{1}{2}(1.41 + 1.4)$$
$$M_{Equ} = 1.405\,Nm$$

The equivalent bending moment of the shaft is that moment which when acting alone produces the same tensile or compressive stress (σ_b) as the actual bending moment

$$M_{Equ} = \frac{\pi}{32} \times \sigma_b \times d^3 \qquad (12)$$

Where σ_b=maximum allowable bending stress of shaft which is 30MPa (Marks, 2004)
d=diameter of the shaft

From this expression the diameter of the shaft is evaluated:

$$1.405 = \frac{\pi}{32} \times 30 \times 10^6 \times D_s^3$$
$$D_s = 7.8mm$$

3.5. Determination of the Handle Parameters

It is made of a cylinder steel pipe of diameter (D_h) 20mm, which can be adjustable for the operator's convenience. The handle is subjected to both axial and bending forces due to the inclined position. The length of the handle is determined from (Krisha, 2008):

$$\frac{M_b}{I} = \frac{\sigma_b}{c} \qquad (13)$$

For a steel handle, σ_y=yield stress= 294.2MPa
Assume, Factor of safety of 2.5

$$\sigma_b = \frac{\sigma_y}{FOS} = \frac{294.2}{2.5} = 117.68MPa$$

$$c = \frac{D_h}{2} = \frac{0.02}{2} = 0.01\text{m}$$

$$\frac{64FL_h}{\pi D_h^4} = \frac{117.68}{0.01}$$

$$F = 50N$$
$$\frac{64 \times 50 \times L_h}{\pi 0.02^4} = \frac{117.68 \times 10^6}{0.01}$$
$$L_h = 1.85m$$

Where M_b = bending moment = FL_h
I = moment of inertia for handle, $I = \frac{\pi D_h^4}{64}$
$C = \frac{D_h}{2}$
σ_b= allowable bending stress

$$\sigma_b = \frac{\sigma_y}{FOS}$$

3.6. Determination of the Power Requirement

Power required to overcome grass cutting resistance (P_1) (Khurmi, 2003):

$$P_1 = \frac{T \times 2\pi N}{60} \quad (14)$$

$$T = shaft\ torque = 0.77Nm$$

$$N_{reel} = N_{pinion} = N_{Shaft} = 715rpm$$

$$P_1 = \frac{0.77 \times 2 \times \pi \times 715}{60}$$

$$P_1 = 57.7watts$$

Power required to overcome inertia in pushing the machine to motion (P_2) (Krisha, 2008):

$$P_2 = M_m \times g \times f \quad (15)$$

$$m_m = mass\ of\ machine = 20kg$$

$$f = velocity\ of\ machine = 0.8m/s$$

g= acceleration due to gravity = 9.81

$$P_2 = 20 \times 9.81 \times 0.8$$

$$P_2 = 156.96watts$$

Overall power requirement (P)

$$P = P_1 + P_2$$

$$P = 57.7 + 156.96 = 214.6\ W$$

3.7. Determination of the Field Efficiency

Theoretical field capacity = $forward\ speed\ \times theoretical\ width.$

Effective field capacity $= \frac{Actual\ area\ covered}{Total\ time\ taken}$

Field efficiency $\eta = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100\%$

Therefore:

Theoretical field capacity = $0.8m/s \times 0.4m = 0.32\,m^2/s$

Effective field capacity $= \frac{10m^2}{50s} = 0.2\,m^2/s$

Field efficiency $\eta = \frac{0.20}{0.32} \times 100 = 62.5\%$

4. MATERIAL SELECTION, PROCUREMENT AND MANUFACTURE

The choice of material for the design of the reel lawn mower was aimed at achieving high efficiency. This was achieved by selecting the appropriate materials with adequate working condition and stability of the component. Also, materials used for the fabrication of the machine were locally sourced. The materials were purchased in-line with the design specifications. The manufacturing process is discussed briefly.

The Frames: The marked-out measurements were cut-off using a cutting disc attached to a buffer. The specified points to be drilled on the frame were then drilled using a portable hand drilling machine. The rough edged of the frame were grinded using a pedestal grinding machine.

Internal Spur Gear and Pinion: The gears for the power transmission were manufactured to precision using a rotary milling machine. The main gear (also called the annular gear) was milled to have to a total number of teeth as 83 while the smaller gear (i.e., the pinion) was milled to have a total number of teeth as 15. This was made so, in order to obtain a higher gear ratio for effective grass cutting to be ensured. Thus, when the pinion gear meshes with the annular gear, an increased cutting speed is achieved.

The Spiders: The spiders (3 in numbers) served as the housing configuration onto which the reel blades are welded. It is made up of mild steel, of diameter 110mm and with a thickness of 2mm respectively. It was measured and cut to sizes using a steel rule, a scriber and a cutting disc attached to a buffer. The unwanted edges ware discarded using a hand file.

The blades: The dimensions of the helical blades were measured and marked-out to the appropriate sizes. The marked-out measurements were cut-off using an oxy-acetylene gas flame. The helical blades were twisted at a helix angle of 10^o around the spiders in a specific order. The helical blades were then welded to the spider using oxy-acetylene welding machine. The edges of the helical blades were filed using a portable grinder. The design specification of the bed knife was obtained using a measuring tape, permanent marker and was cut-off using a hacksaw. Holes of diameter 5mm was drilled using a drill bit mounted on a vertical drilling machine. These holes accommodate the bolts and nuts used in holding the bed knife to the frame. The bed knife was equally filed to ensure adequate sharpness of the cutting edges.

Handle: A cylindrical steel pipe was measured and marked-out using a measuring tape and scriber to form the handle. The marked-out dimension was cut-off using a hacksaw and bent to specification using a bending machine. Foam was glued to cover the upper section of the handle for operator's comfort.

The following components were not manufactured but were bought off-shelf; the wheels (2 driving and 2 rear wheels), ball bearings (of diameter 20mm), screws, bolts and nuts.

5. MAINTENANCE

Proper maintenance is important for a safe and reliable operation of any machine. Machine maintenance and servicing operation are the measures employed to keep a machine in good working condition and to correct any abnormality that could arise during operation of such machines. Considering the operation of the reel lawn mower, it is important to carry out following maintenance check for proper and effective operation of the mower.

1. Regular sharpening of the reel blades should be ensured for efficient grass cutting.
2. Temporary joints like bolts and nuts should be well tightened to avoid structural damage to the machine
3. After usage in clearing fresh grasses, the machine should be properly cleaned and dried with a clean dry rag before storage to avoid failure caused by corrosion.
4. During operation, the proper setup is for an operator to push the machine with the reel blades in front to avoid stepping on the blades.
5. Before mowing, it should be ensured that the lawn is free from all forms of obstructions like large stones, wooden objects, glasses etc., in order not to damage the blades.
6. After usage, the mower should be stored and kept in a safe place, far from the reach of children because of the exposed blades.

6. COST ANALYSIS

Table 2: Bill of Engineering Measurements and Evaluation

S/No	Component	Material	Dimensions (mm)	Qty	Unit cost (N)	Total cost (N)
1	Driving wheels	Mild steel & rubber	250 mm diameter	2	2,000	4,000
2	Rear wheels	Rubber	100 mm diameter	2	1,000	2,000
3	Ball Bearings	Stainless steel	20 mm diameter	4	500	2,000
4	Bolts and nuts	Mild steel	M18	10	50	500
5	Gear	Mild steel	200mm & 30mm pitch circle diameter with a face width of	2	2,500	5,000
6	Handle Rod	Mild steel	25 mm diameter	1	500	500
7	Solid Shaft	Mild steel	18 mm diameter	1	1,000	1,000
8	Fixed Blade	Mild steel	4 mm gauge	1	2,000	2,000
9	Reel Blade	Mild steel	4 mm gauge	1	2,000	2,000
10	Frame	Mild steel	4mm gauge	1	2,000	2,000
11	Blade Spider	Mild steel	4mm gauge	1	2,000	2,000
			Total			**23,000**

Table 3: Labour Cost

S/No	Component	Machine operation	Qty	Unit cost (N)	Total cost (N)
1	Gear	Turning, facing and milling	2	7,500	15,000
2	Handle rod	Cutting and bending	1	500	500
3	Fixed blade	Cutting and filing	1	1,000	1,000
4	Reel blade	Cutting, filing and twisting	6	1,160	7,000
5	Frame	Cutting and Drilling	2	750	1,500
6	Blade spider	Cutting and Filing	3	650	2,000
		Total			**27,000**

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Table 4: Total Cost

S/No	Description	Amount (N)
1	Materials	23,000
2	Labour	27,000
3	Miscellaneous	10,000
Total		60,000

7. PERFORMANCE EVALUATION

The performance of the manually powered lawn mower machine was evaluated through a field test. The test was conducted in the Engineering field of the University of Benin, covered predominantly with three different species of grasses; stubborn grass, spear grass and carpet grass. The field was mapped out into plots of 4000mm x 2000mm. Five of these plots were selected by randomization process and mowed. A stop watch was used, noting the time spent cutting the field.

Theoretical Field Capacity $FC_t = W \times S$
Where W=width of cut = 0.4m
S= speed of machine =0.8m/s
$FC_t = 0.4 \times 0.8 = 0.32 m^2/s$

Effective Field Capacity, $FC_e = \frac{Actual\ area\ covered}{Total\ time\ taken}$

Field Efficiency $\eta = \frac{effective\ field\ capacity}{theoretical\ field\ capacity} \times 100\%$

The test results obtained from the field test is shown in Table 5

Table 5: Results of effective field capacity (FC_e) and field efficiency (%)

Plot No.	Area (m^2)	Time (sec)	FC_e (m^2/s)	FC_t (m^2/s)	Field Efficiency (%)
1	8	39.60	0.204	0.32	63.750
2	8	39.30	0.202	0.32	63.125
3	8	39.48	0.203	0.32	63.438
4	8	39.00	0.201	0.32	62.813
5	8	39.75	0.205	0.32	64.063

$$\text{Average Field Efficiency (\%)} = \frac{317.189}{5} = 63.44\%$$

The performance test of the non-mechanized reel lawn mower presented in Table 5 indicates the value of the computed effective field capacity (FC_e) and field efficiency (%). The highest effective field capacity is obtained as $0.205 m^2/s$ and field efficiency as 64.063% with operating time of 39.75secs. This may be due to variations in level of moisture content during the time field operation. The theoretical field capacity (FC_t) of the mower was calculated to be 0.32 m^2/s with forward speed of 0.8m/s and the width of cut of 0.4m.

4. CONCLUSION

The non-mechanized reel lawn mower was designed, fabricated and tested. It does not have an electric or internal combustion engine which meets the challenge of "Environmental Production" (reducing or eliminating green-house gas emissions that causes climate change) and low cost of operation since no cost is incurred for fueling. Performance test and Evaluation revealed a field efficiency of about 63.44 percent (%). Higher grass cutting efficiency was obtained when the lawn is dry (low moisture content) and having less undulating nature of field surface. This machine powered by manual pushing can be used by both rural and urban dwellers. The cost of the machine including material and fabrication cost is sixty thousand naira (#60,000). When it is mass produced, the cost of the machine could get in more affordable price, making it far cheaper than most conventional lawn mowers.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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