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Study, design and construction of a motorized weeder for rice fields

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Abstract

This article discusses the design and construction of a motorized weeder to make weeding easier during rice production by reducing producers' efforts and thus optimizing the yield of rice production in Benin. The purpose of this study was motivated by a practical observation concerning the arduousness of manual weeding in rice fields. Indeed, during the upkeep period of rice cultivation, if herbicides are not used, farmers hand pull out weeds, exposing themselves to numerous diseases. The design process of the motorized weeder was presented and resulted in the realization of this equipment. The results of the study will enable rice fields to be weeded without difficulty and in a time-saving manner, which will undoubtedly lead to an optimization of rice production yield.

Keywords: Motorized weeder, weeding, paddy cultivation, rice field maintenance.

Introduction

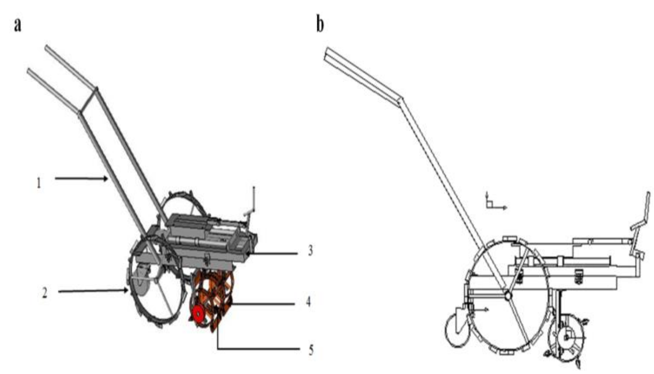
Rice is the third most important cereal produced in the world after wheat and maize and is the staple diet of nearly 40% of the world's population[1,2]. It is the food mainstay for more than 2.5 billion people in developing countries, with an average consumption of 55kg of rice per capita per year over the last decade[3].

In Benin, rice production accounts for a large proportion of agricultural production and has a double economic and social stake in terms of marketing, food security and, without any doubt, the battle against poverty. On the one hand, it generates significant agricultural income and on the other hand, rice has become a preferred food in both urban and rural households. In the past, rice was considered a luxury food, mainly consumed on holidays, and it is now an increasingly important part of people's diets. Nowadays, rice enjoys great political interest in the development of agricultural sectors[4]. However, the rice sector is encountering many technical difficulties, particularly in its weeding methods. Producers devote more hours to weeding than to any other type of work in developing countries such as Benin[5]. So far, weeding has remained essentially manual despite the multiplicity of weeding machines that exist. Although efficient, imported rice weeding technologies do not respond to prevailing national realities, and the few local weeding methods (manual weeding) remain less efficient. The weeding process depends on several factors such as: the financial situation of the farmer, the farmer's know-how, the topography of the land, the size of their acreage, the availability of labour and working time, the service delivery agency[6].

The present study aims to continue the research carried out by Assema into the design of a manual weeder and to analyse existing weeding methods and principles, while proposing equipment that meets the conditions of small-scale rice producers in the sub-region and Benin in particular[7]. The study aims to develop a motorized rice weeder that enables farmers to increase their production capacity while reducing paddy maintenance time.

Methodology

Specification of the designed machine: Figure-1 is a sketch designed in the Top Solid environment of the weeder to be built.



(1): guide arm; (2): drive wheels; (3): belt tension adjusting device; (4): blade; (5): weeding assembly.
Figure-1: Representation of the weeder: (a) Synoptic diagram of the weeder, (b): Plan drawing of the weeder.

The main components of the complete weeder are the frame, weeding unit, blades, drive wheels, petrol engine and belt tension adjusting device. The drive wheels and blades provide the ground clearance of the machine. The path of the weeder in the field is the space between two rows of rice plants[8].

Frame: The frame is mainly made with angles to guarantee stability. It serves as a support for the weeding assembly and the engine and ensures that the machine is kept at an acceptable height for the user in paddy fields[9].

Weeding assembly: The weeding assembly consists of hoops on which the blades are mounted by means of the blade holders. The use of the blade holders makes it easier to change the blades in case of wear and tear.

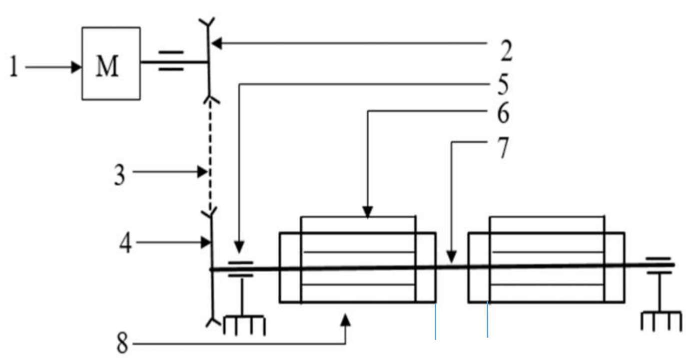
Blades: They are used to cut unwanted herbs. The cutting width is 120mm. They are inclined at 28° to the horizontal as with a plough and at 127° to the vertical, which is the angle of inclination of a hoe[10].

Drive wheels: They are used to drive the weeder and to prevent the machine from slipping on muddy ground[11].

Petrol engine: It powers the weeding unit via the pulley-belt drive and the shaft.

Belt tension adjusting device: It is used to tension or slacken the belt. It consists of a lever, a motor support sliding on another non-moving support fixed on the frame.

Principle of operation: Figure-2 is the drive chain of the weeder. It shows the operating principle of the weeder. When the motor (M) is switched on, the shaft (7) is rotated by the belt (3). Once in contact with the ground, the blades (6) of the weeding unit (7) cut the weeds and bury them in the soil. The weeds are thus cut and covered with soil by the rotating action of the blades.



1: Heat engine; 2: Driven pulley; 3: Belt; 4: Driven pulley; 5: Bearing; 6: Blades; 7: Shaft; 8: Weeding assembly.

Figure-2: Drive chain of the weeder.

Modeling: This part is devoted to the identification of mathematical models relating to the various components of the weeder. These models reflect the physical phenomena that govern the operation of the components.

Weeding assembly: The essential parameters of the weeding assembly are the cutting force of the weeds, the forward speed, the power output and the torque of the unit.

Weeds cutting force: To evaluate weeds cutting force, weeding tests were carried out with the manual prototype manufactured in the workshop. During the trials with five different normal individuals (individuals with good physical fitness), the force that each operator exerted on the prototype for the equipment to cut the weeds was evaluated. In this study, simplifying assumptions were made to facilitate the calculations. Thus, the cutting force is assumed to be less than or equal to 20% of their muscular force and takes into account the state of the soil (muddy), the force required to push and drive the tool into the ground.

$$F_c = 20\%\, F_m \qquad (1)$$

F_c: cutting force, F_m: muscular force

Forward speed of the weeding assembly: During the 5 trials, for one round of the weeding unit, the time and distance covered were recorded (Table-4). The forward speed is the ratio between the average distance travelled and the average time required to complete the journey.

$$V_{mean} = \frac{d_{mean}}{t_{mean}} \qquad (2)$$

With: V_{mean}: average forward speed in *(m/s)*, d_{mean}: average distance covered *(m)* et t_{mean} : average running time in *(s).*

Power output: The power output (P_u) of the weeding unit is the product of the cutting force and the average forward speed.

$$P_u = F_c.V_{mean} \quad \text{(W)} \qquad (3)$$

Torque of the weeding unit: The torque of cutting writes:

$$C_c = F_c.L \qquad (4)$$

With C_c meaning the torque of cutting (*N.mm)*, *L* the motor shaft length in *mm*.

Drive chain: The transmission chain is made up of several types of transmissions that transform the engine power and determine the speed required for the proper operation of the work machine. It is characterized by two parameters, namely the overall efficiency and the transmission ratio. The type of transmission used on here is V-belt pulley transmission.

Overall efficiency: The overall efficiency writes (5):

$$n_g = n_{pal} x\, n_{co} \qquad (5)$$

With n_{pal} is the efficiency in pairs of bearings and n_{co} the efficiency of V-belts[15].

Transmission ratio: The driving ratio is determined as:

$$R_g = \frac{N_a}{N_m} = \frac{d_m}{d_a} \quad (6)$$

With N_a meaning the shaft speed of the weeding unit in rpm, N_m the engine shaft speed in rpm, d_m the diameter of the motor pulley (mm) and d_a the diameter of the pulley in mm.

Engine: The engine plays an important role in the design of the weeder. The parameters that govern it are its power and speed[12]. The latter determine the choice of the right engine for the weeder.

Motor power P_m: The power of the Pm engine can be written as follows:

$$n_g = \frac{P_u}{P_m} \quad (7)$$

From relation (7), P_m can be found:

$$P_m = \frac{P_u}{n_g} \quad (8)$$

Engine speed: From the average speed, the shaft rotation frequency can be determined as[5]:

$$N_a = \frac{60\ V_{mean}}{\pi\ x\ d_{ar}} \quad (9)$$

With, *Na:* engine speed, d_{ar}, the diameter of the selected shaft (here d_{ar}=14mm)[7].

Equations (6) and (9) lead to:

$$N_m = \frac{60V_{mean}}{\pi \times d_{ar} \times R_g} \quad (10)$$

Shafts I and II: Two shafts are mandatory for the proper functioning of the drive train. The parameters of the drive train are power, speed and torque on each shaft. Thus:

$$C = \frac{P}{\omega} = \frac{60P}{2\pi N} \quad (11)$$

P is the engine power, (W)

Shaft II: Shaft II is the one carrying the weeding unit.

$$N_2 = N_a \text{ and } P_2 = P_m * n_g \quad (12)$$

Sizing of drive belts: The transmission of the engine's movement to the other components will be via V-belts. A belt is characterised by its cross-section, pitch length, centre distance, winding angle and maximum power rating (Figure-3)[13].

Selection of the belt section: The selection of the belt section is based on the operating power (P_s) and the speed of the small pulley (N_m). The expression of the operating power is[14]:

$$P_s = k_s\ x\ P \quad (13)$$

With k_s, representing the service factor, which depends on the type of engine and receiver components and the daily operating time, and *P* is the engine power. Knowing the values of P_s and Nm, one refers to the graph of the ranges of transmissible power per belt type to select the belt section[14].

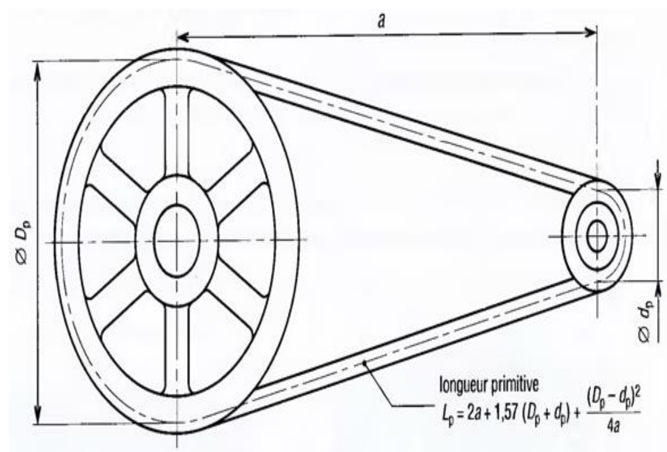


Figure-3: Scheme of belt drive[15]

Calculation of the belt interaxial distance: The inter axial distance is the distance between the axes of the two pulleys. In order to determine the centre distance a, its minimum value (a_{min}) and maximum value (a_{max}) must first be determined.

When the ratio D_p/d_p is between 1 and 3 (as in the current case), a_{min} and a_{max} are determined by relations (14) and (15).

With D_p and d_p meaning respectively the primitive diameters of the large and small pulley:

$$a_{mini} \geq \frac{D_p + d_p}{2} + d_p \quad (14)$$

$$a_{maxi} < 3(D_p + d_p) \quad (15)$$

After determining a_{mini} and a_{maxi}, an approximate value is chosen for the interaxial distance such as:

$$a_{mini} \leq a < a_{maxi}$$

The axes of the pulleys being parallel and the belt not crossed, the primitive length L_p of the belt is written[17]:

$$L_p = 2a + 1{,}57(D_p + d_p) + \frac{(D_p - d_p)^2}{4a} \quad (16)$$

After calculating L_p, the table with indicative pitch lengths of V-belts is used to select a length that is normalized to the calculated theoretical length[15].

From the normalized pitch length, the actual centre distance of the belt is calculated as follows:

$$a_r = \frac{L-\frac{\pi}{2}(D_p+d_p)}{2} - \frac{(D_p-d_p)^2}{4[L-\frac{\pi}{2}(D_p+d_p)]} \quad (17)$$

Calculation of the basis power P_b: The basis power P_b is a function of the linear speed V_c and the pitch diameter dp of the small pulley. Let us therefore determine V_c:

$$V_c = \omega_d . \frac{d_p}{2} \quad (18)$$

However $\omega_d = \frac{2\pi N_d}{60}$ (19)

Then $V_c = \frac{\pi N_d}{30} (\frac{d_p}{2})$ (20)

With respectively ω_d and N_d the angular velocity and the rotational frequency of the small pulley.

Based on the table showing the basis power P_b (in kW) of conventional V-belts[15], P_b is selected taking into account the calculated V_c and d_p.

Calculation of the wrap angle θ: The wrap angle is the angular deviation between the belt direction and the horizontal (figure 4). It is determined by the following formula:

$$\theta = 180° - 2sin^{-1} [\frac{D_p - d_p}{2a_r}] \quad (21)$$

Calculation of the permissible power *Pa*[15]: Calculation of the permissible power Pa is determined as below:

$$P_a = P_b . K_L . K_\theta \quad (22)$$

With: K_L: weighting function primitive length, K_θ: weighting function of the angle of wrap,

Calculation of the number of belts N_c: The number of belts is derived from the permissible power Pa and the operating power

$$N_c = \frac{P_s}{P_a} \quad (23)$$

Pulleys: The system to be designed consists of two pulleys of different diameters (Figure-4). The parameters considered for the pulleys are the weight and the forces that the pulleys exert on the belts.

Weight of the pulleys: The pulleys are made of aluminium alloys. Let ρ = 2,7 kg/dm^3, the density of the pulleys and P_{px} the weight of the pulley[15]. Suppose that the pulleys are cylindrical without cells of diameter d_x and height equal to the thickness b of the pulley. The weight can be determined by the formula:

$$P_{px} = \rho . g . \frac{d^2{}_x . \pi . b}{4} \quad (24)$$

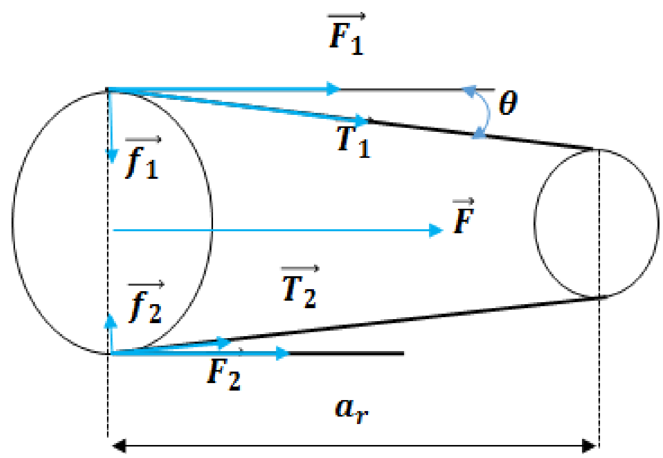


Figure-4: Belt action on pulleys.

Forces generated by the pulleys: The belt that connects the two pulleys admits one tight strand and one loose strand. Let T_1 be the tension in the stretched strand, T_2 the tension in the slack strand.

At start up (Figure-4) on a $T_1 > T_2$. In order to simplify the calculations, some assumptions have been made.

Assumptions:

$T_1 = 2T_2$; $f_1 = 2f_2$ and $F_1 = 2F_2$ (25)

$\vec{F_1}$ is the horizontal component of $\vec{T_1}$

$\vec{f_1}$ is the upright component of $\vec{T_1}$

$\vec{F_2}$ is the horizontal component of $\vec{T_2}$

$\vec{f_2}$ is the upright component of $\vec{T_2}$

The torque C exerted by the forces ($\vec{F_1}, \vec{F_2}$) is determined by the following relation:

$$C = (F_1 - F_2)\frac{D}{2} \quad (26)$$

By operating (24) and (25), the resulting force F generated by the belt in the horizontal direction is determined:

$$F = \frac{6C}{D} \quad (27)$$

(D represents the diameter of the large pulley).

According to figure 4:

$$f_1 = F_1 . tan\ \theta \text{ and } \vec{F} = \vec{F_1} + \vec{F_2} \quad (28)$$

From the relations (27) and (28), f_1 writes:

$$f_1 = \frac{4\ Ctan\theta}{D} \quad (29)$$

Taking into account that:

$$f = f_1 + f_2 \quad (30)$$

Combining relations (29) and (30) gives:

$$f = \frac{6C \tan\theta}{D} \quad (31)$$

With $\tan\theta = \frac{D-d}{2a_r}$

Shaft of the weeding assembly: During normal operation, the shaft of the weeding unit is subject to bending, twisting and shearing. They must therefore simultaneously respect the conditions of resistance to the three (3) physical phenomena mentioned above. Therefore:

Resistance to torsion:

$$\tau_t \leq R_{pg}$$

$$d \geq \sqrt[3]{\frac{16 * C_{max}}{\pi * R_{pg}}} \quad (32)$$

Resistance to bending

$$\sigma_f \leq R_p$$

$$d \geq \sqrt[3]{\frac{32 * M_{fmax}}{\pi * R_p}} \quad (33)$$

Shear resistance

$$\tau_c \leq R_{pg}$$

$$d \geq \sqrt{\frac{4 * T_{max}}{\pi * R_{pg}}} \quad (34)$$

With M_{fmax} the maximum bending moment, T_{max} the maximum shear force, C_{max} the maximum torque on the shaft of the weeding assembly, and R_{pg} the practical slip resistance of the steel used for the shaft.

After calculating the diameter in all three cases, the standard diameter immediately above the value of the largest of the three is selected[16].

Estimated cost of the Weeder: The overall cost (C_g) of the machine will be evaluated according to: i. The cost (C_m) of the raw materials used and the cost (C_p) of the standard parts and accessories; ii. The cost (C_u) of machining the parts; iii. The cost (C_b) of the design office.

In other words:

$$C_g = C_m + C_p + C_u + C_b \quad (35)$$

Results and discussion

Results: The results from the application of the mathematical models of the units making up the weeder are given in Tables 1, 2, 3, 4, 5, 6, 7, 8, 9 and the estimated cost of the weeder in Table 10.

Table-1: Values of the characteristic parameters of the weeding assembly.

Component	Parameters			
	Torque force *Fc* (N)	Average speed V_{moy} (m/s)	Power output *Pu* (W)	Cutting torque *Cc* (N.m)
Weeding unit	111.45	0 .76	84.7	37.22

Table-2: Values of the characteristic parameters of the drive train.

Component	Parameters		
	Efficiency		Transmission ratio (R_g)
	Bearing (n_{pal})	Belt (n_{co})	
Drive chain	0.97	0.96	0.65
	Global efficiency l (n_g)		
	0.93		

Table-3: Values of Motor Characteristic Parameters.

Component	Parameters	
	Motor power P_m (W)	Engine speed N_m (tr/mn)
Engine	90.96	1036.78

Table-4: Values of shaft characteristic parameters.

Component	Parameters		
	Spindle speed (rpm)	Power (W)	Torque (N.m)
Shaft I	$N_1 = 2000$	$P_1 = 1104$	$C_1 = 5,27$
Shaft II	$N_2 = 1036.78$	$P_2 = 1028.04$	$C_2 = 9.46$

Table-5: Values of the characteristic parameters of the pulleys.

Component	Parameters			
Pulleys	Weight of the driving pulley (N)	Weight of driven pulley (N)	Resulting force generated by the belt in the horizontal direction (N)	Resulting force generated by the belt in the upright direction (N)
	$P_{pm} = 3.37$	$P_{pa} = 8.15$	$F = 1595.14$	$f = 89.328$

Table-6: Values of the characteristic parameters of the drive belt.

Component	Parameters			
Drive belt	Operating power P_s (kW)	Linear velocity V_c (m/s)	Center distance (mm)	
	1.435	9.42	$a_{mini} \geq 205$ mm	$a_{maxii} < 690$ mm
			Approximate centre Distance (mm) a = 440	
			Actual center distance (mm) $a_r = 440$	

Table-7: Values of the characteristic parameters of the power transmission belt.

Component	Parameters				
Drive belt	Primitive length L_p (mm)	Wrap angle θ (°)	Basis Power P_b (kW)	Permissible power P_a (kW)	Number of belts N_c
	1250	173.54	2.052	1.95	1

Table-8: Values of the characteristic parameters of the shaft of the weeding assembly.

Component	Parameters			
Weeding unit shaft	Maximum torque C_{maxi} (N.m)	Shear forces T_{max} (N)	Maximum bending moment M_{fmax} (N.m)	Practical slip resistance R_{pg} (MPa)
	37.224	1598.11	31.98	47

Table-9: Values of the characteristic parameters of the weeding unit tree shaft.

Component	Parameters			
Weeding unit shaft	Diameter *d* (mm)			Length *L* (mm)
	Resistance to torsion	Resistance to bending	Shear strength	= .34
	≥ 15.91	≥ 15.13	≥ 6.57	
		Selected diameter: 16		

Table-10: Cost of the weeder.

Cost of raw materials, standard parts and accessories ($)	Cost of machining parts ($)	Study and design costs ($)	Total cost of the machine ($)
259	17	42	318

Data analysis: The engine: The desired characteristics of the motor for the weeder are therefore: N_m= 1595.38 rpm and P_m = 90.96 W.

For safety reasons (risk of overload) and the fact that the values calculated do not appear in the standard range of engine characteristics, the immediately higher engine power was selected[17] i.e. the Robin petrol engine whose rated power is P_m= 1.5 HP, meaning P_m=1104 W, with a rated speed of 2000 rpm.

The shaft of the weeding unit: Since the sized diameter of our shaft must be greater than or equal to 15.91 mm, a standardized diameter $d = 16\ mm$ was chosen, according to the Industrial Designer's Guide[16].

The permissible belt power: According to the table showing the basis power $P_b$in KW of conventional V-belts[14], the diameter of the selected small pulley is not directly suitable for a basis power. The basis power corresponding to the diameter of the small pulley was first determined using an interpolation method. Then by the same method, the base power corresponding to the linear speed of the belt was determined.

Study and design costs: The cost of the design office was estimated at 15% of the cost of raw materials, standard parts, accessories and machined parts.

The cost of the weeder: A financial evaluation of the weeder is approximately $318. Given the spending power of a rural household in Benin, estimated at $1653 per year, rice producers will be unable to afford such a weeder[18]. The government should support the producers with subsidies.

Conclusion

This work carried out will make it possible, in a sustainable way, to improve the income of rice production in Benin by limiting the time of weeding, to protect workers from the dangers of manual weeding, to limit the labour force and to fight against the accelerated use of chemical products for weeding. The manufacture of the proposed equipment is expected to have considerable socio-economic benefits for producers in particular and will open up many local business opportunities in general. Two advantages emerge from this design work. Indeed, the weeder will not only allow producers to easily eliminate weeds, but it will also stir up the soil and destroy weeds that will then decompose to feed the soil. In view of the high cost of the weeder, it would be desirable for the State to play its part by accompanying the construction of the weeder to enable its extension and the promotion of local production in Benin[19].

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